

AN INTEGRATED BUILDING SYSTEM  
FOR HIGHER EDUCATIONAL FACILITIES

by

CHARLES FRANCIS DAVIS, III  
B. Arch. (Honors Program) Auburn University  
(1962)

SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE  
DEGREE OF MASTER OF  
ARCHITECTURE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 1966

Signature of Author . . . . .  
Department of Architecture, August 15, 1966

Certified by . . . . . Thesis Supervisor

Accepted by . . . . .  
Dean of the School of Architecture and Planning

## ABSTRACT

That buildings must be designed in terms of flexibility is the most basic premise of this thesis. From it all else follows. Considering that the life span of a large building as constructed in these times is a minimum of one hundred years, it becomes obvious that change within the building will occur. In higher educational facilities it is commonly accepted that five per cent of the floor area of a building is affected by change annually. In some institutions it may even be greater. Extending this rate of change over the life of the building yields a forecast of one complete change each twenty years or a minimum of five changes during the life of the building.

The fact that change will affect a small portion of a building each year does not make complete ease of change a necessity, but that change occurs at all demands the design of buildings whose organization is capable of being altered without destroying its value. However, the conclusions that the need for flexibility should be an overriding consideration in all buildings is false, for in certain building types this need may not exist at all or may exist only in certain parts. In educational and research facilities, and office buildings, for example, change will occur and basic provisions for it must be made. To provide this flexibility designers must cease making buildings as solutions to particular, absolute sets of programmatic requirements. Furthermore, they must de-emphasize the differences among buildings of the same type and concentrate on their similarities. When this is begun the whole area of systems design as

applied to architecture is opened up.

Such a direction leads to the design of a building matrix composed of a set of integrated systems which is adaptable within predetermined limits to different habitation usages. The building matrix must be capable of handling the greatest demands placed upon the design, and thus its implementation becomes more costly as the range of adaptability increases.

The adaptability required of the matrix has two aspects. The first is in the building design phase. The matrix should enable the formulation of many different planning and sectional variants in order to meet varied programmatic requirements.\* The second aspect is meaningful after a particular building is constructed. Here the matrix should enable changes in planning layouts to occur with relative ease as well as additions to the building volume. This twofold adaptability should be the basic criteria for designing the matrix.

It must be remembered that the justification of this building matrix approach is based on the need to accommodate change. To show its financial repercussions is beyond the scope of this research. It involves a detailed comparison of construction and adaptation costs of a particular solution using this approach versus a more conventional approach.

---

\* Planning and sectional variants for the matrix developed are shown in Plates 13 and 14.

### ACKNOWLEDGMENTS

To Professor Eduardo Catalano, I am grateful for his criticism and advice during the development of this thesis. His experience and professional competence set exceptionally high standards of excellence. I am grateful to Mr. Wacław Zalewski for his creative and exciting approach to structural designs. His wisdom was constantly a source of amazement and challenge. His sense of humor in the times of lost heads was indispensable. To my wife - whose newfound skill in the casting of cement proved invaluable to the completion of the model - my gratitude knows no bounds.

## TABLE OF CONTENTS

	<u>Page</u>
Abstract	1
Acknowledgements	3
Table of Contents	4
List of Plates	5
I. The Building Matrix	6
A. Structural Span	6
B. Mechanical Systems	7
C. Planning Module	8
D. Applicability	9
II. The Structural System	10
A. Design Criteria	10
B. Design Concept	11
C. Economy	12
D. Basic Precast Elements	12
E. Erection Procedure	17
III. Mechanical Systems	19
A. Air Conditioning	20
B. Plumbing	23
C. Lighting	23
D. Sound Absorption and Insulation	24
IV. Vertical Circulation Cores	25
Appendix A	Alternate Girder Designs
Appendix B	Alternate Column Designs
Appendix C	Formwork for Precast Concrete Elements

## LIST OF PLATES

<u>Plate No.</u>		<u>Page</u>
1	Basic Precast Elements	26
2	Erection Procedure - Step 1	27
3	Erection Procedure - Step 2	28
4	Erection Procedure - Step 5	29
5	Erection Procedure - Step 6	30
6	Erection Procedure - Step 7	31
7	Erection Procedure - Step 8	32
8	Core Elements	33
9	Core Elements	34
10	Core Variants	35
11	Core Variants	36
12	Core Variants	37
13	Core Spacing Variants	38
14	Sectional Variants	39
15	Components of the Building System	40
16	Mechanical Structural Integration at Section "A-A"	41
17	Mechanical Structural Integration at Section "B-B"	42
18	Mechanical Structural Integration at Section "C-C"	43
19	Mechanical Structural Integration at Section "D-D"	44
20	Construction Details	45
21	Construction Details	46
22	Axonometric of Assemblage	47

## I. THE BUILDING MATRIX

The matrix described below is a system of building for higher educational facilities in that the structural span, mechanical systems, lighting intensities, space planning modules and cores were determined to solve the general needs of such facilities.

### A. Structural Span

The first consideration in setting the structural span was that almost all of the spaces needed could be formed without any special construction. If there are more than a few spaces which cannot be provided by the structural system then the system is not adaptable and its existence cannot be justified. On this basis the minimum span was determined to be 45 feet but not to exceed 60 feet. The second consideration was the depth of space required for air and plumbing distribution. This dimension was placed in the range of two and a half to three and a half feet using low velocity horizontal distribution from the columns or high velocity from the cores. These dimensions would be increased if low velocity distribution from the cores were to be used and decreased in the case of high velocity distribution from the columns. If a full three foot ceiling to floor height is used structurally, a span of sixty feet can be achieved at a 1:20 depth-span ratio. The third consideration because universities today are able to finance buildings with parking areas but are hard pressed to find funds for a parking garage alone. There are ample parking arrangements available within the forty-five to sixty foot limits but perpendicular parking at sixty feet

is the most economical. Therefore at a span of around sixty feet these three considerations come together to reinforce the decisiveness of one another.

In setting the span and structure there was one other question to be answered. Should the sixty feet dimension exist in only one direction or both? The choice results in either adaptability being accommodated more easily in one direction than in the other or equal design and growth potential in both directions. The possibilities of increases in materials and labor needed to achieve this two directional freedom was also considered. The decision was made to sacrifice economy to the added advantages of two way construction.

#### B. Mechanical Systems

The mechanical systems can exist in three different relationships to the structure: free from the structure, bound to the structure, or free within the structure. The first is excluded by the previous decision to use the entire ceiling to floor height for structure. The second is appealing intellectually but this direct relationship limits the opportunities to change systems at a later date when a more economic one may become available and necessary. The third allows the use of the entire floor depth for structure and allows the use of various systems in different applications of the adoption of another system at a later date.

If freedom exists, the application of various airconditioning systems is practically universal. In a particular installation one would be chosen over another



on the basis of economy in initial costs, maintenance and operation costs, and adaptation costs. Conditions may vary from one time to another and from one place to another. Consequently, more important than choosing a particular system is the ordering of a distribution pattern that is adaptable to various systems and the establishing of limits of control. The mechanical system described in this thesis is a modest one, but it can handle most situations to be incurred in higher educational facilities. The area of the control zone, 1800 square feet, is at the upper limit, and could be reduced to 900 square feet if deemed necessary to meet abnormal demands on the system.

### C. Planning Module

The choice of a planning module is based primarily upon the size and range of sizes required for the smaller spaces and paths of circulation. Since a priori the structural and planning module should coincide, there is the additional criteria of structural economy.\* A third and perhaps minor consideration is the lighting module.

The smallest habitable space in educational facilities will generally be no smaller than 80 to 100 square feet with the shortest wall being eight to ten feet long. The next size space should be no smaller than 130 to 150 square feet in area. Corridor widths could be limited to three different ranges: four to five feet for intraoffice corridors, eight to twelve feet for most other corridors, and fifteen to twenty feet for major

---

\* The choice of a two way structure predetermines the use of a square planning module. This is an advantage since the square module will provide two directional flexibility.

circulation areas. These requirements could be satisfied with modules up to five feet.\* Lighting fixture modules in this range are two, three, and four feet. The four foot module is preferred because it requires fewer fixtures and is consequently more economical. If the fixtures are to be placed between the horizontal structural elements, the planning module will have a minimum dimension of 4'-6" or 4'-8".

For a span in the range of sixty feet, a structural module of eight to ten feet would be economical. One possible way to avoid the conflict which is appearing between the planning and structural modules would be to keep the structure at ten feet and to establish a planning module at five feet by adding minor elements spanning between the structural members. Under close analysis it seems that this procedure requires more material than the smaller structural module, and consequently the conflict seems inevitable. Need again was placed above economy and a module of five feet was chosen.

#### D. Applicability

Although the building matrix described below is one answer to a general building type, it has a much broader range of applicability. It is especially adaptable to multi-story buildings up to six or seven stories with large floor areas. Economically it is most feasible for building types with spatial and flexibility requirements similar to those stated above.

---

\* If a six foot square module had been chosen, for example, the smallest habitable space would have been 144 square feet and the next largest would have been 216 square feet. If nine feet had been taken then the smallest space would have been 81 square feet, and the next largest generally usable space would have been 324 square feet. Also neither of these works well for corridor widths.

## II. THE STRUCTURAL SYSTEM

Reinforced concrete alone was considered for the structural material of the system. This decision is a beginning point and is left without defense or justification. However, it is worth noting several of its advantages over steel. Concrete is its own fireproofing. Concrete and precasting plants can be or will shortly be found in all areas due to the relatively small investment required for their construction. Concrete is a prefinished material. Since it is a cast material, it is easily molded into the form required.

Precast was chosen over cast in place concrete because it provides greater speed in on site construction; it allows the use of stronger materials and consequently produces lighter structures; and it can take advantage of more recent construction procedures.

### A. Design Criteria

Early in the design phase the following set of criteria was established for the design of a two way precast system. This set was reached abstractly before the designer was biased by an affinity for a particular system.

1. Establish a heirarchy of structure corresponding to:
  - a. Structural behavior
  - b. Assembly procedure
  - c. Required openings
2. Design structural members for ease of forming, casting, transportation and assembly.

3. Keep number of pieces and joints to a minimum
4. Keep post stressing operations to a minimum
5. Eliminate scaffolding
6. Establish continuity of structure
7. Allow ducts and piping to move without conflict within the structure.

#### B. Design Concept

The concept of the structural system is quite simple and is the outgrowth of the criteria established above. The design followed quite naturally the realization that the member which carries the floor load directly to the column is in fact a girder and carries many times the load carried by most other horizontal elements. Calculations showed that the moments decreased toward the center of the span in the following proportions:  $M$  (moment in the girder),  $0.375 M$ ,  $0.250M$ ,  $0.125 M$ ,  $0.042 M$ ,  $0.006 M$ . The resulting system had elements in two directions spanning across a bay bounded by four girders with those in one direction above the other set.

The moments in the girders was of a magnitude of 3,600 kip feet. By post stressing the maximum moment could be reduced to 2,000 kip feet, which was still excessive for the 3'-6" depth which had already been determined as a reasonable depth. It was decided to reduce the moment in each girder by splitting each in half and having sets of double girders carry the floor loads to the columns (Plate 22). As a result, the differences between the moments in the girder and the interior elements was reduced by one half.

This change called for a rethinking of the system

and subsequent analysis led to the use of elements of equal strength and rigidity spanning between the girders in both directions. This results in two overlapping one way structural systems normal to one another. Each system carries one half of the floor load. The moments in the secondary elements is 13.6% of the moment in the girder. This allows much lighter elements spanning between the girders with the same reinforcing throughout.

#### C. Economy

It should be stated that this is not as economic a use of materials as a one-way structure would have been. For the infill between the girders approximately twenty per cent less material would be needed if the beams in one direction had been doubled in strength to carry the entire load above them and the beams in the other direction had been deleted. In order to extend the efficiency, the girders would have to have been shorter, and this would result in the addition of columns at approximately thirty feet on center in one direction. This is, of course, in conflict with the basic design criteria of equal flexibility in both directions. For this reason it is not to the point to compare the economy of this structural system with that of a one-way structure. The difficiency that this system does offer is a result of ease in forming, pouring, transportation and assembly, not of material. It would be applicable only when two directional flexibility is required and would be feasible only if economy of labor outweighs material economy.

#### D. Basic Precast Elements

The basic elements of the structural system are columes, girders, lower and upper beams, filler slabs at

the girders, and the edge beams (Plate 1). Each element has been designed to facilitate forming, pouring and erection procedures. There were other alternatives for columns and girders which under slightly different conditions and criteria could be applicable. These are shown in Appendices A and B.

## 1. Column

The column is made of four identical pieces, each being two stories high. The pieces are placed to enclose a four foot square shaft which is used for vertical circulation of air, water and waste. Placed in sets of opposite pairs, the column pieces are assembled so that adjacent ones begin and end a floor from each other. This overlapping establishes a structural continuity without joints at each level. Each piece has steel angles anchored in the corners which touch the adjacent pieces. These are welded to one another to provide rigidity and the possibility for loads to be transferred from one piece to the other when necessary. Precasting of the column may be done easily with the form in a horizontal position (Appendix C). This will produce a screeded finish on the one side which would be placed facing the interior of the column.

## 2. Girders

Girders occur on a 5', 55', 5', 55', . . . module in both directions (Plate 15). The five foot dimension corresponds to the column width and this space between the girders is used to carry major mechanical services. As mentioned above, the doubling up of girders further

allows the 55 foot span to be resolved within the depth deemed reasonable and with an element that can be lifted easily by a crane.

The girders spanning in one direction are slightly different from those spanning in the other, (Plate 16 and 18). The differences are a result first of the problem of having two linear elements, the girders, end at the same point. This need was accommodated by having one girder (girder "B") rest directly on top of the columns and the second girder (girder "A") rest on top of the first (Plate 20). Because of the size of the moment and the size of the openings required in the girders, it was decided to design the girder as a quasi-truss. As a result of the differing end conditions it was necessary to place openings in the upper half of girder "B" and in the lower half of girder "A". This relationship satisfies another criteria. It allows the mechanical services to pass through the girder at points both above and below the center of the structural floor, and to feed out into the center of the span within either the upper or the lower layer of structural members (Plates 18 and 19).

The girders have notches in the top to receive the supported beams. Thus the structural joints are near the finished floor level and are easily accessible. The notches, furthermore, make accurate placement of the beams a rather simple matter. In the final stages of construction the depth of the girder is extended to the full floor depth through post tensioning over the column and by extending the reinforcing steel out into the slab over the full length of the girder.

Formwork for the girders is relatively simple (Appendix C). Each side form has projections half of the

thickness of the girder which correspond to the openings in the girder. Thus when the two sides are in place the projections create voids in the girder. The sides are simply pulled away to unmold the girder. The notches in the top are formed by individual inserts placed and removed from the top. To insure economy in the formwork of the girders, they have been designed so that by simply inverting the side forms both types of girders may be formed. The only other differences to be accommodated are the end conditions, which may be handled through interchangeable inserts.

## 2. Structural Floor

The double layered floor structure spans between the four girders. The lower beams have greater height at each end to enable it to be supported at the top of the girder. The particular angle used allows the trussing of reinforcing bars to provide negative steel over the double girder (Plate 21). Shallow notches are provided in the top of the beams at points where the upper layer crosses. These match corresponding notches in the upper beams to allow for differences in deflection under each members own weight. Any gap will be grouted so that under additional loading the two layers will act together. The upper beams, being tee sections, have less depth than the lower beams due to a greater moment of inertia of the section per unit of height. The total depth of the tee sections is increased by the concrete topping, bound to the tees by reinforcing steel extending beyond the top of the section. Five feet from each end steel has been trussed up to provide negative steel over the double girders (Plate 21).

The joint between the two layers of structure, as



shown in Plates 21 and 22 is simple in concept but difficult to construct. These plates show rods projecting out of the beams and extending up through the web of the tee beams. Because of the possibility of bars bending and the difficulty of aligning the bars with the holes in the tees, such a solution is not feasible. To accomplish the same ends with much less difficulty, it would be possible to cast inserts in the beams. Then, after the tee sections are in place, a bolt could be dropped down through the tee and tightened.

Restudy seems to show that a connection to insure equal deflection in both layers at each point is unnecessary. This is due to the fact that the greatest portion of the load by far is an evenly distributed dead and live load. Thus equal deflection is a fait accompli. A concentrated load is distributed in two directions from the point where the load is applied. The joint based on this criteria is very simple. It is only required to transmit compression and to restrain any buckling tendency in the lower beams. Such a detail could make the construction procedure simpler, reduce construction time, and consequently reduce costs.

### 3. Filler Slabs

The floor between the double girders is formed and carried by shallow tee sections (filler slabs). They are supported in the notches in which the beams rest. The space between the end of these and the end of the beams is grouted. Over the top of the shallow tees reinforcing steel is placed and welded to the steel extending out of the beams (Plate 21). This produces a couple which reduces the moment in the beams by approximately twenty per cent or enough to carry a ten foot cantilever.

#### 4. Edge Beams

The edge beams are one half as deep as the total floor (Plates 18 and 20). They are supported by the girders at the same level as the elements they carry. During construction the edge beams are shored up to restrict their deflection under loading until the negative steel over the shallow tees is in place and the topping is poured. This procedure is followed to reduce the moment in the beams of the first interior span. Since deflection due to live loads in these cantilevered areas would be negligible, the negative steel would not work to any significant extent unless the dead load as well is carried through the negative moment.

The depth of the edge beams allows one edge beam to pass over another and thus allows the formation of an interior corner. However, it restricts cantilevers to twenty feet beyond the girders. The size of the smallest opening is restricted to fifteen feet square if it is placed in the center of the span. Openings, which are not centered in the span, would be greater. It seems that neither of these is a serious limitation on flexibility. In any case, they are much less restricting than having no interior corners except at the girders.

#### E. Erection Procedure

The following is a listing of the erection procedure to be used for this structural system. At each floor one set of opposite pieces in each column extends to the next level.

1. Second set of two story high column pieces

- are placed, and grouted, and steel for continuity is welded (Plate 2)
2. "B" girders are placed (Plate 3)
  3. "A" girders are placed
  4. Joints between girders and columns are grouted
  5. Edge beams are placed (Plate 4)
  6. Lower beams are placed (Plate 5)
  7. Tee beams are placed (Plate 6)
  8. Shallow beams are placed between pairs of girders (Plate 7)
  9. Steel is placed over shallow tees and welded to steel extending from the beams
  10. Reinforcing for the topping and cables for the post-tensioning of girders are placed
  11. Concrete topping is poured
  12. Girder is post-tensioned.

A great deal of time and emphasis was placed in finding variations within the same idea. The final presentation is not necessarily better than other variations shown in Appendicies A and B. It was chosen as an example of the idea because it is of a medium complexity.

### III. MECHANICAL SYSTEMS

There exist two basic approaches to the design of a mechanical system within this structure. The first combines the air conditioning ducts and pipes within the same spaces. This approach leads to conflicts between the two elements. Both must pass through the same openings and between the same girders and beams. For this reason the alternative approach of separating ducts and pipes into different structural layers was chosen. The difficult problem is in choosing which will occupy which layer. For several reasons, placing the pipes in the upper layer seemed to be the more reasonable choice. From a functional point of view, normally pipes feed up to the floor above and ducts to the spaces below. If the pipes occupy the lower layer, maintaining the required slopes to the column would have become a problem. Thirdly, from a visual point of view, it is more acceptable to see ducts which can be of constant size and location than pipes which occur in an indeterminate manner. Lastly, the standard size and location of ducts allows the use of standard panels which increase the wall height between the lower beams.

The only problem to be solved then is to make the ducts appearance unobjectionable. This is not a serious problem because the lighting fixtures used will cover most of the ductwork and because their relative brightness diminishes the visual importance of the ducts. Since the ducts are unobtrusive, the problem centers around the normal unfinished appearance of ducts in comparison to the structure, lighting fixtures, and partitioning. It is hoped that having the diffusers built into the ducts will give the desired finished quality.

## A. Air Conditioning

The mechanical system described in the next few paragraphs does not represent the only system that will fit the structure or necessarily the best for all situations. Depending on exact design criteria established for a particular application another system may be used quite easily. This is one of the advantages of the structural system.

### 1. Interior Zone

The system described uses an 1800 square foot area as the minimum control zone, (Plate 15). Within this area individual space control is afforded through electric coils within the duct of diffuser serving the space. The coil or coils are controlled by a thermostat within the space. Exact placement of the reheating elements would be made according to space planning and the range of demand on the system within the control zone. The electric coils and thermostats would be secondary, removable elements. For example, if within one control zone there occurred only individual offices for one person and at no time would there be more than two persons in any space, then a thermostat placed in one space could adequately control the air supply for all the spaces. If varying types of spaces replaced these identical spaces within the control zone, electric coils would probably be introduced. If design criteria called for greater ease of flexibility, then either the control zone would be reduced or a more expensive system could be used, such as a dual duct high velocity system with mixing boxes.

The air conditioning system shown has supply and return air ducts placed in alternating columns in a

checkerboard pattern.\* This arrangement provides supply and return to any portion of the building wherever the perimeter occurs (Plate 15). These vertical ducts carry conditioned air at 5000 feet per minute and return air at 3500 feet per minute. At each floor on either side of the vertical supply duct there are attenuators where the velocity is reduced to 1500 feet per minute and the volume is controlled for the two thirty by sixty feet areas at each side. The controlling thermostat will be installed in the space placing the greatest demands on the system. As noted above, for other spaces electric coils with individual space control may be furnished to reheat the air.

From the attenuators the conditioned air moves through the major horizontal ducts, between the "A" girders, to the branch ducts (Plate 16). These ducts, as well as the return air ducts, have strip diffusers built into them at ten feet on center. The grilles are flush with the bottom of the duct, (Plate 18). The air moves at a maximum velocity of 1000 feet per minute in these ducts. The return air ducts are centered between the supply ducts on ten foot spacings. Diffusers are staggered to create a checkerboard pattern which allows a minimum number of diffusers to be used. The diffusers are always evenly spaced across the ceiling. If the supply diffusers are off center, the return registers assure even distribution and circulation of air in the room.

---

\* Since the column houses the ducts, the column size limits the height of the building. In this case, it is limited to seven floors unless a mechanical floor is added from which air is fed up and down. This extends the limit to fourteen floors with one mechanical system.

The ten foot spacing of supply diffusers requires that the duct work be over designed. In a fifteen foot square space there could be one, two or four supply air diffusers in the ceiling. This is not a serious problem for air distribution because of the complementary placement of return air registers but the ducts would have to be able to supply enough air to one diffuser to air condition such a space. A bay is served by two sets of branch ducts feeding from between opposite girders. Since these ducts are a constant size to facilitate standardization, advantage can be taken of the necessity of over designing them by making their termini adjustable. By changing the supply to one diffuser from one set of ducts to the other set, the limits of a control zone can change when necessary to contain a space within one zone.

The return air moves at 700 feet per minute to the major horizontal return duct between the "A" girders and then at 1000 feet per minute to the attenuator adjacent to the vertical duct. Here the velocity is increased to the 3500 feet per minute velocity within the vertical duct.

## 2. Perimeter Zone

The perimeter zone of a building would be handled by an induction system (Plate 15). The high velocity supply air is fed from the same columns used for the interior air supply. The ductwork for interior and perimeter zones should be separate. This assures that the velocity and pressure required for the induction units is always maintained. Hot, cold, and return water lines are supplied to the induction units from the same set of columns.

### 3. Special Problems

In science facilities with large laboratory areas ample space is available for horizontal exhaust ducts but special techniques are necessary to handle vertically the large quantities of exhaust air. Special shafts can be introduced if laboratories are backed up to one another. If laboratories can be placed near vertical circulation cores, ample space within the cores can be allocated for vertical exhaust ducts. Though this problem limits planning flexibility, the solution should not be in oversizing all the elements of the system for this is a special case within the general types of buildings being considered.

#### B. Plumbing

All vertical piping other than that within the vertical circulation cores is within the same columns as the supply air ducts (Plate 15). The major horizontal piping runs are between the double "B" girders consequently, there is no conflict with the major duct work which is between the double "A" girders (Plate 17). From this point piping can run as necessity demands, through any opening in the girders into the center of the span. Because the ductwork in this area is within the lower layer of structure, the two are independent of one another.

#### C. Lighting

The absolute design criteria for illumination design is maintaining an even distribution of light at the correct intensities. The choice of a lighting layout is otherwise a matter of economy and personal preferences.



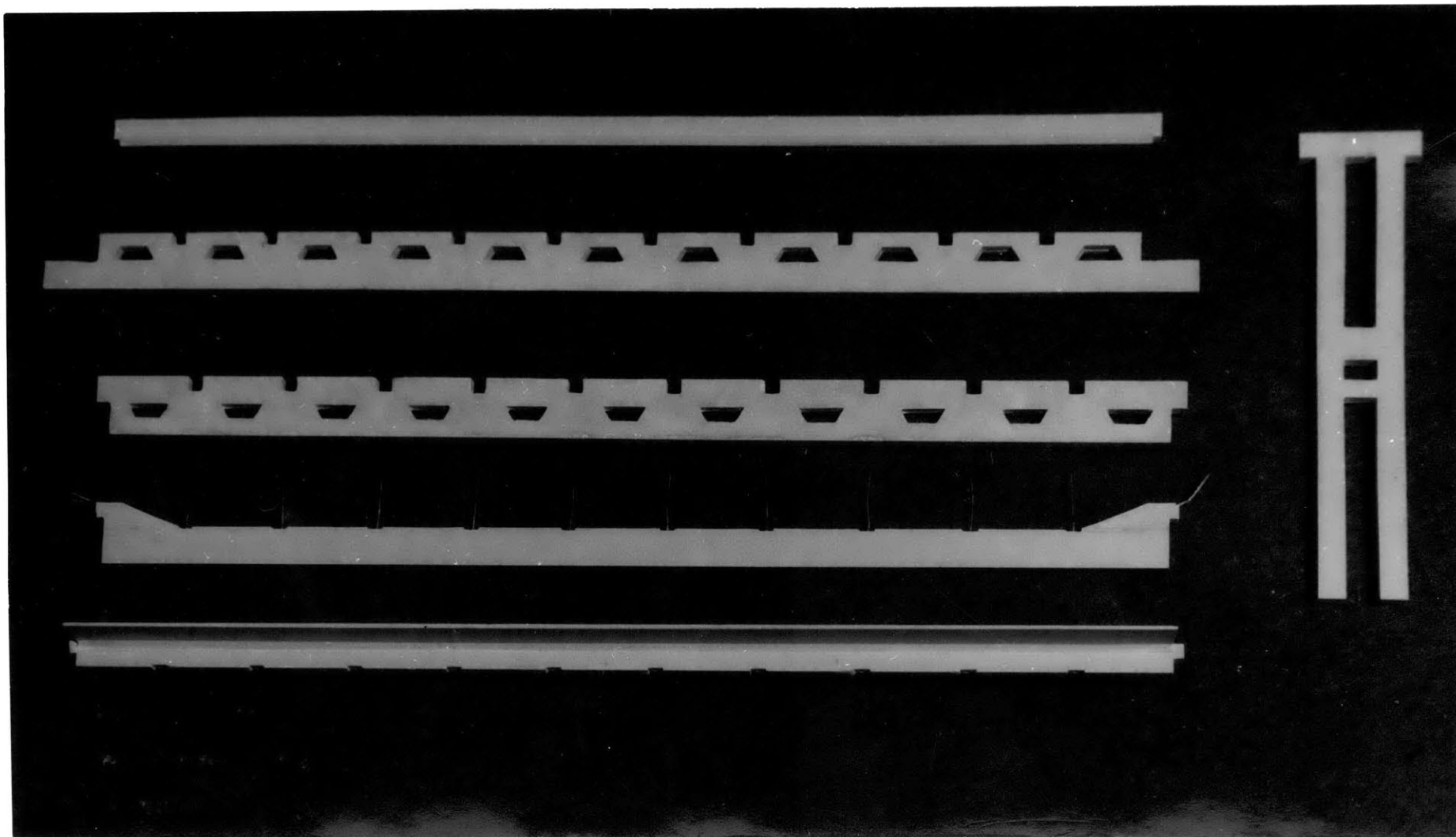
In this particular case, the possibility of placing partitioning at each module must be maintained. The layout shown in the drawings is a checkerboard pattern which assures an even distribution of light in all size spaces (Plate 15). To allow a range of lighting intensities four foot square fluorescent fixtures are used. The possible light intensities are: four tubes, 65 foot candles; six tubes, 100 foot candles; eight tubes, 130 foot candles. This provides an adequate range of intensities for most conditions encountered in higher educational facilities.

#### D. Sound Absorption and Insulation

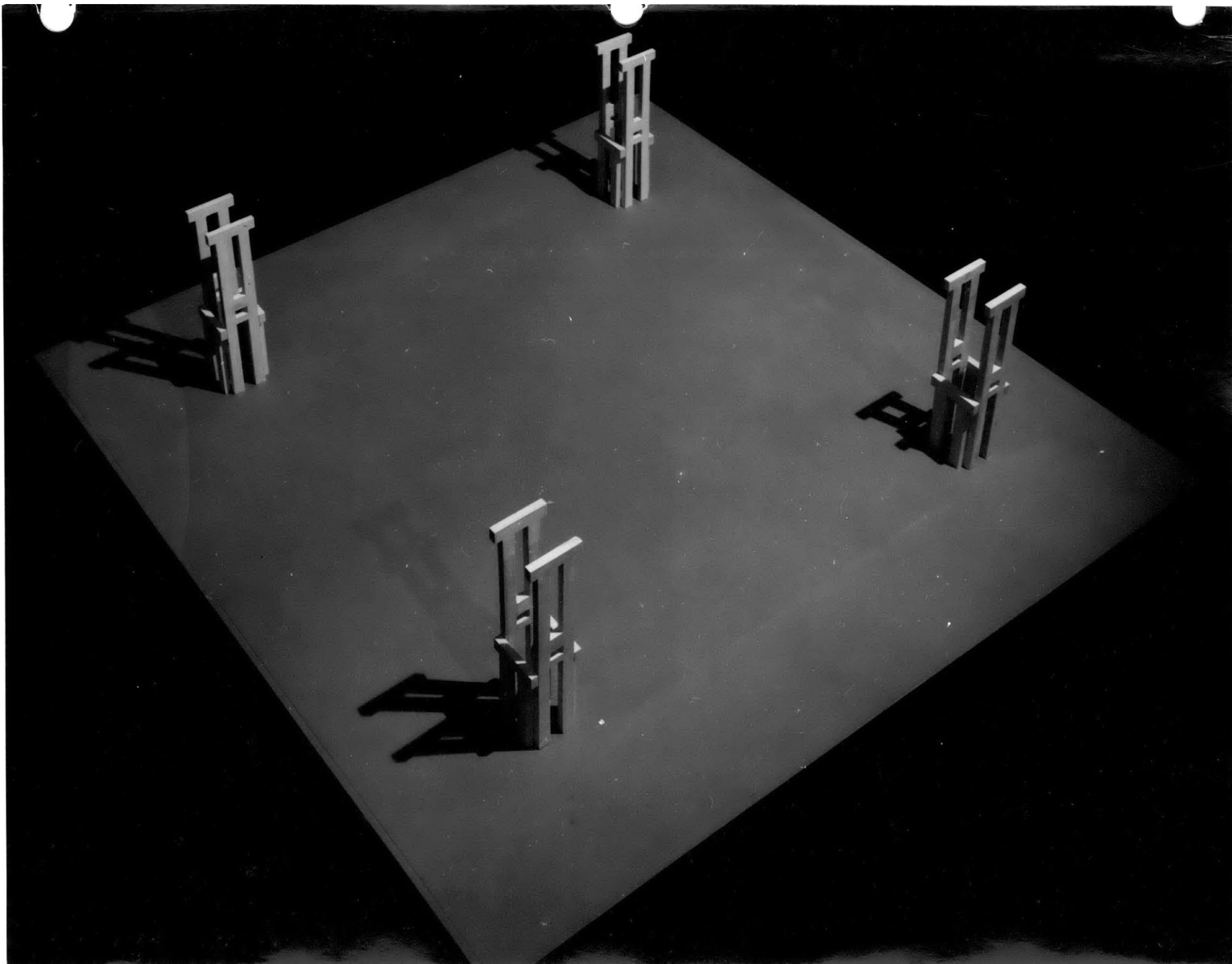
To control noise levels and reverberation times within the spaces sound absorptive material will be applied to either side of panels set on top of the lower beams between the tee sections. The core of the panel will have to be massive enough to prevent unacceptable sound transmission from one space to another. The panels would be prefabricated and set into position after the completion of the structure and plumbing. A matter of detailing is involved in developing a technique for the passage of pipes through the panels. The ceiling is dropped between the double girders to enclose the major duct work and piping. This ceiling would be finished with a sound absorptive material.

#### IV. VERTICAL CIRCULATION CORES

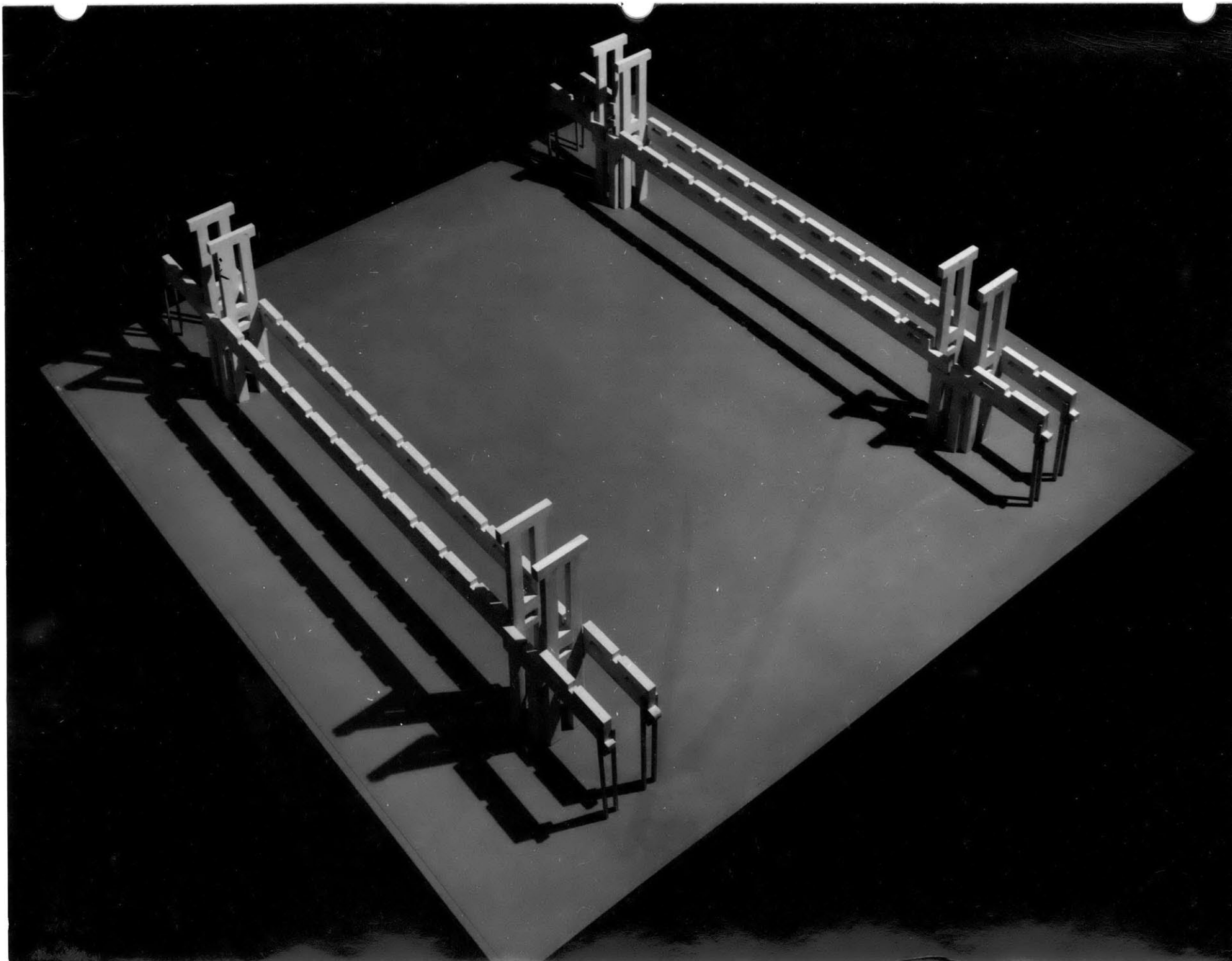
The cores of vertical circulation are made up of component elements which may be combined in various arrangements depending on programmatic requirements. The elements shown were designed for use in a building of six to seven floors in height. Most of the determinants are general enough to be applied to a wide range of building types. The individual elements are shown in Plates 8 and 9 and diagrams of various combinations possible in Plates 10, 11 and 12. Possible effects on building design of various core arrangements are shown in Plate 13.



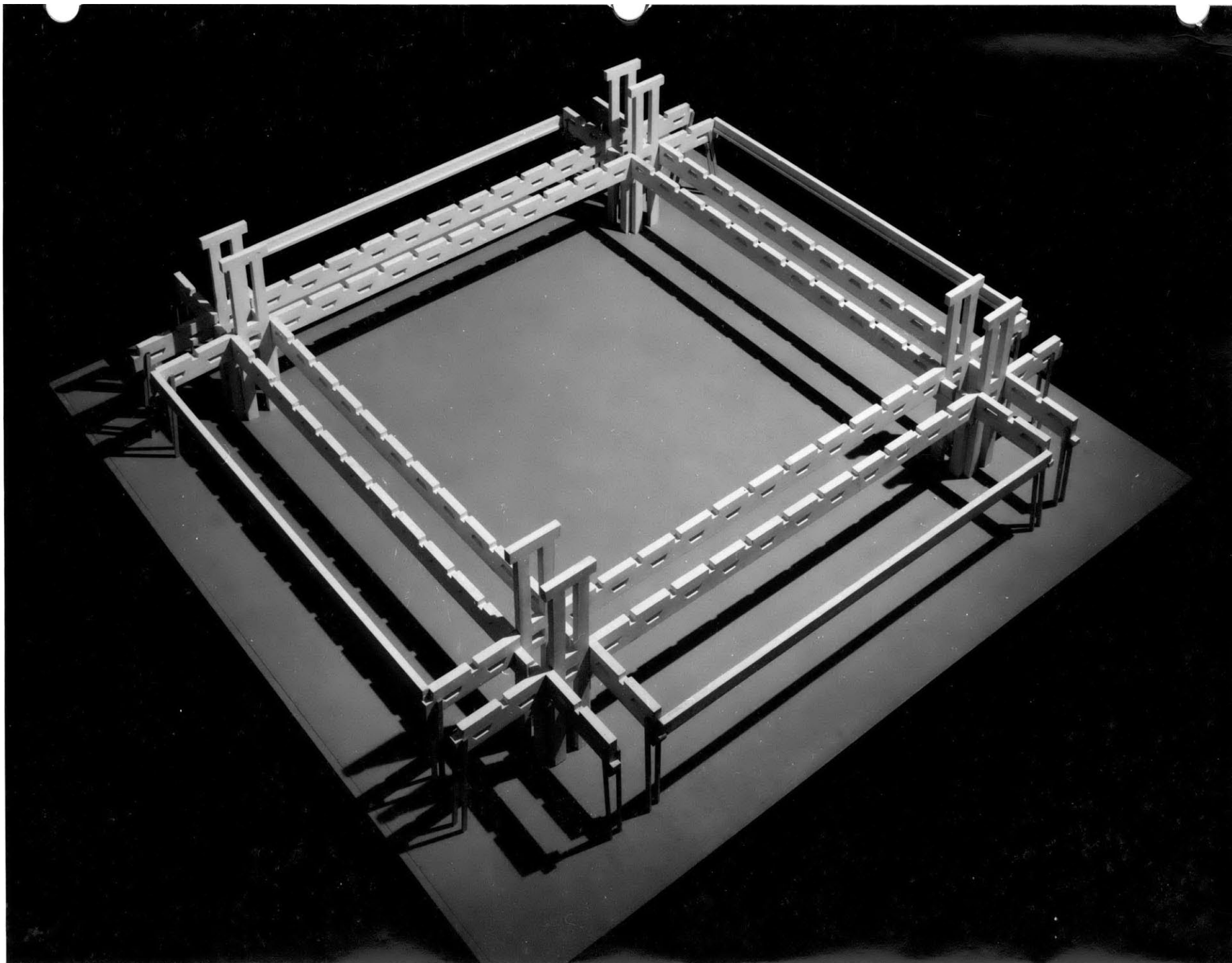
BASIC PRECAST ELEMENTS



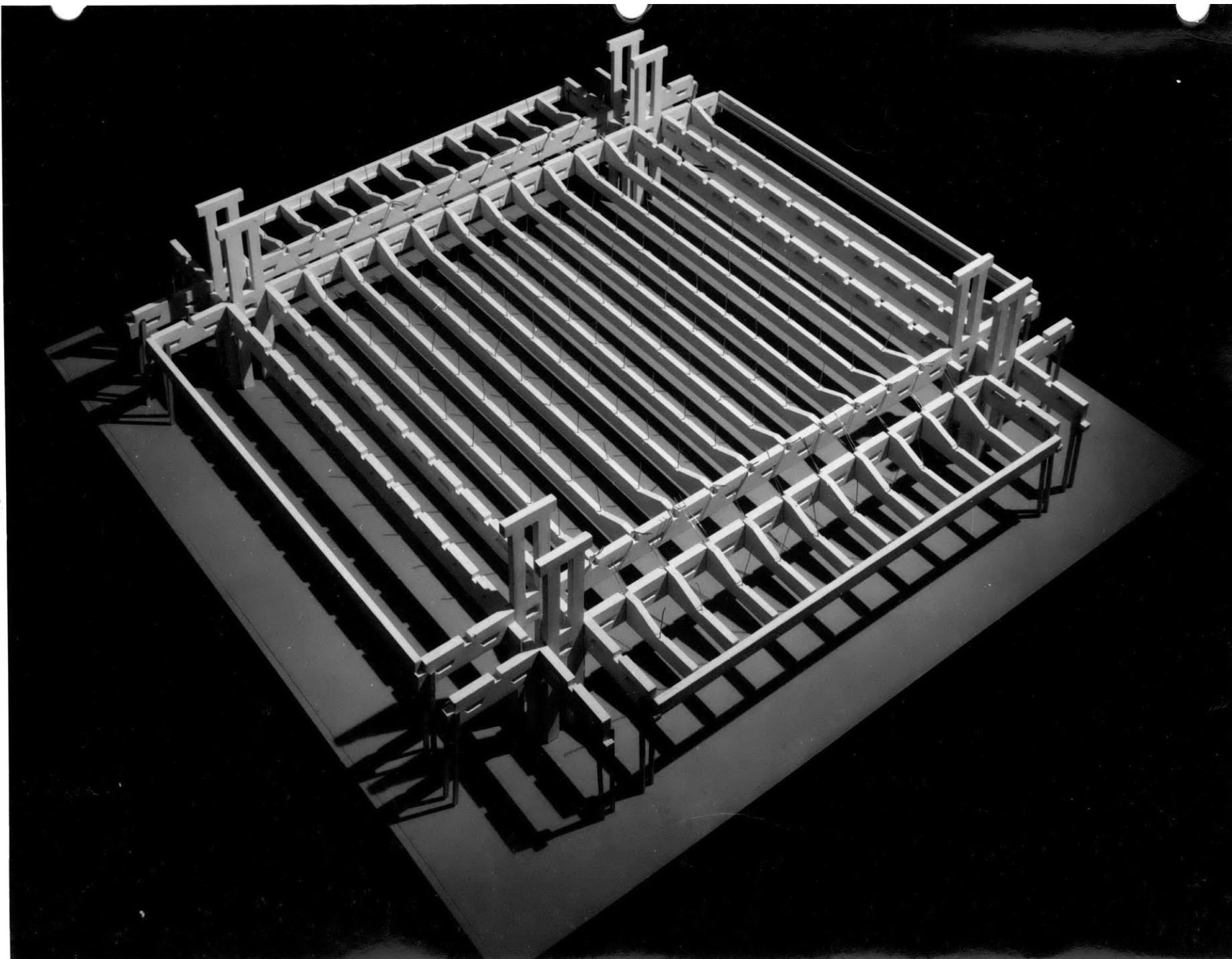
ERECTION PROCEDURE STEP 1



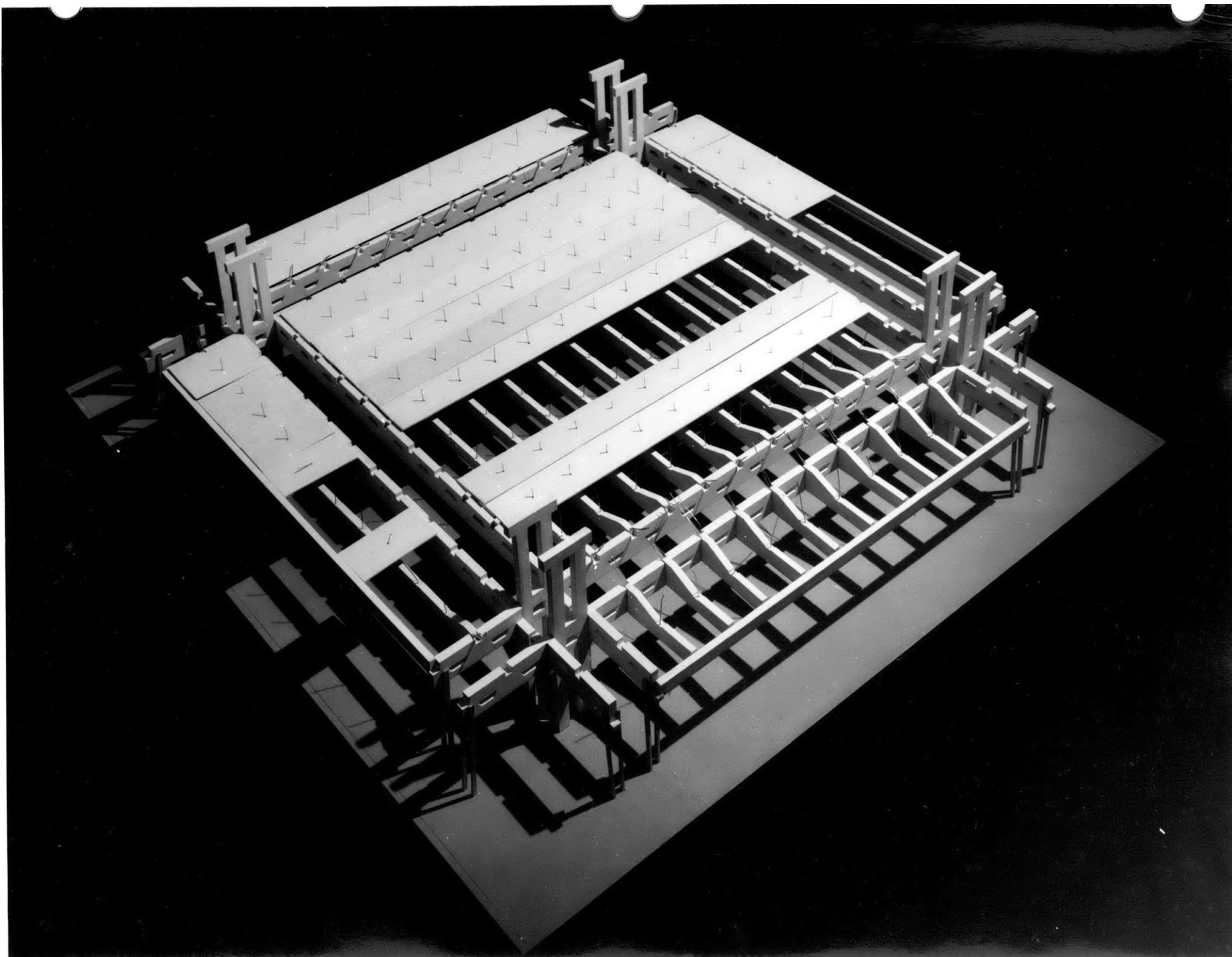
STEP 2



STEP 5

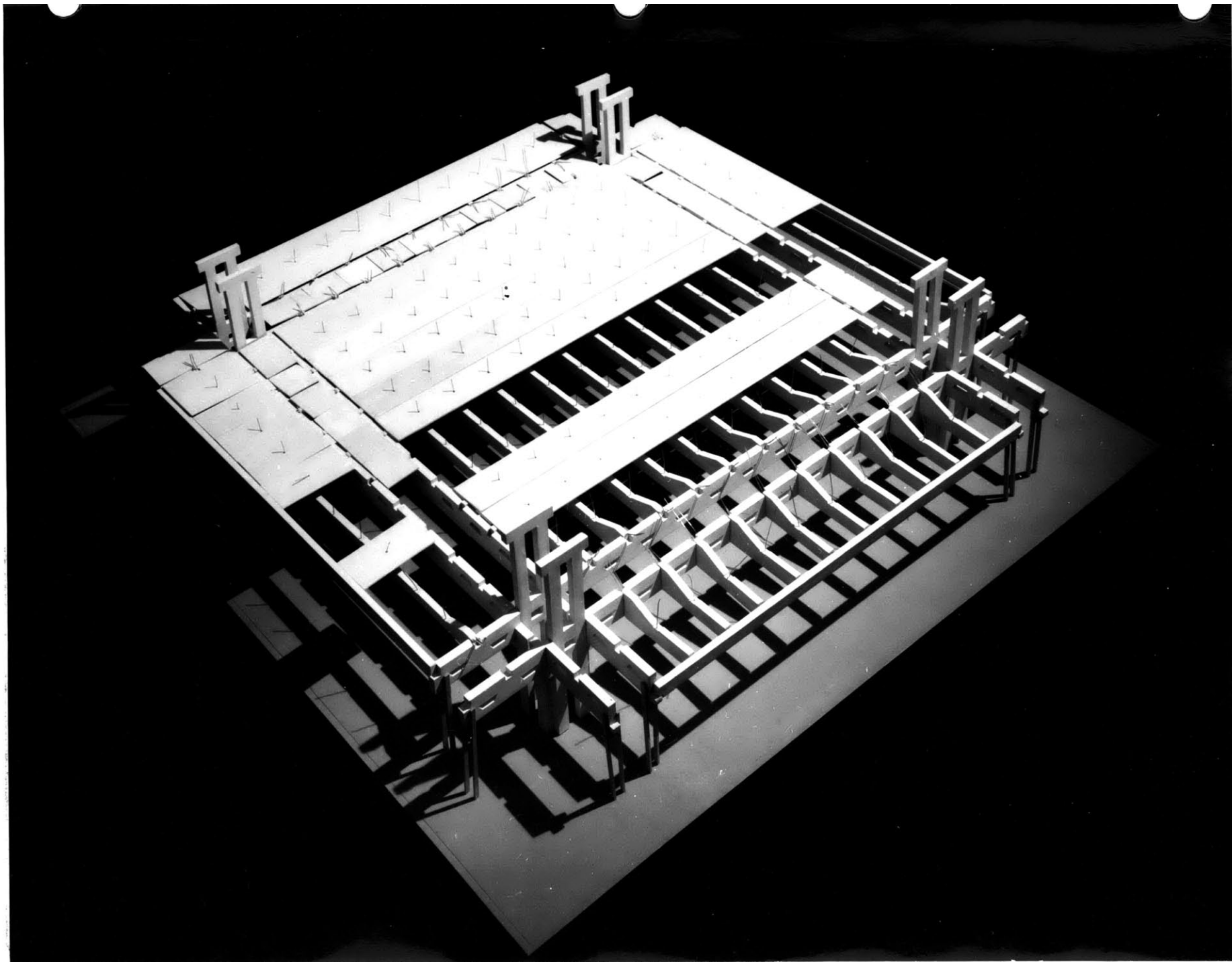




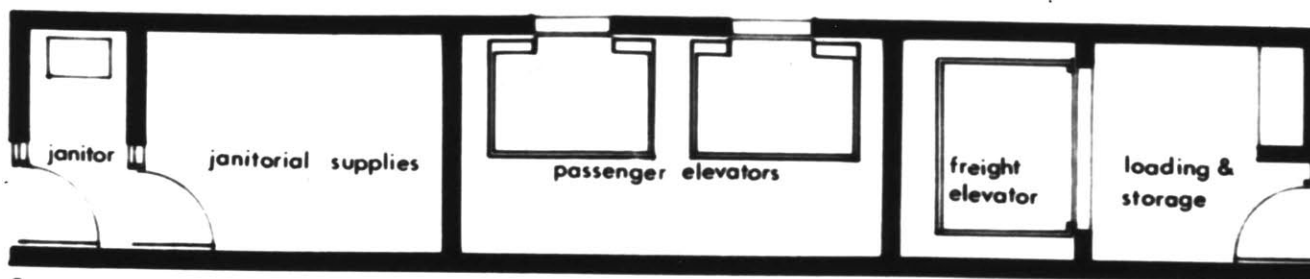


STEP 7

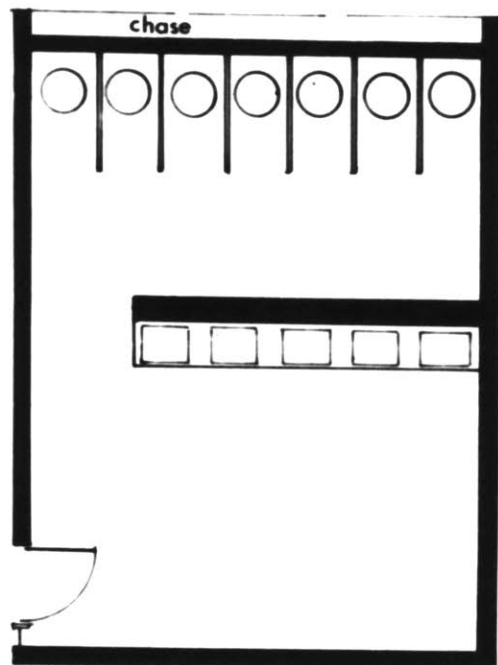




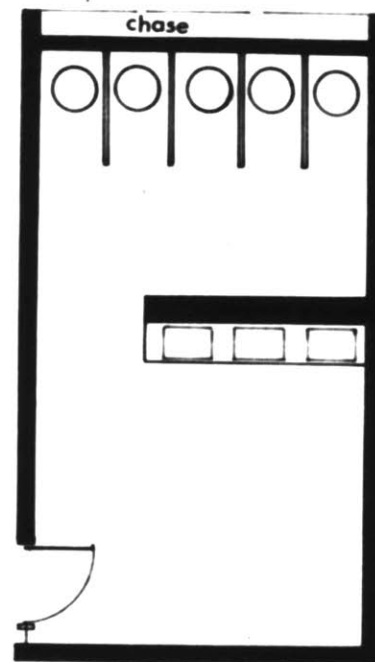
STEP 8



1 ELEVATOR A



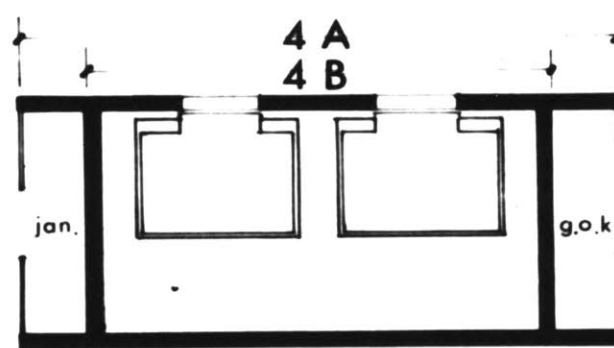
2 TOILET A



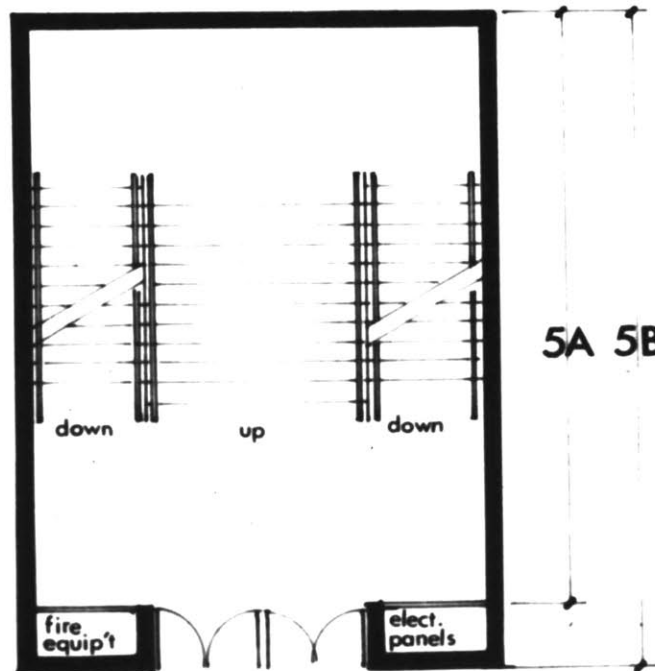
3 TOILET B

# CORE ELEMENTS

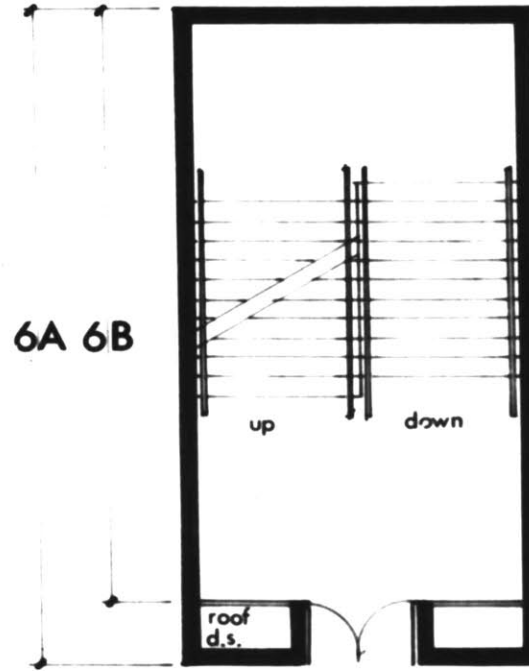
1/8" = 1'



4 ELEVATOR B



5 STAIR A

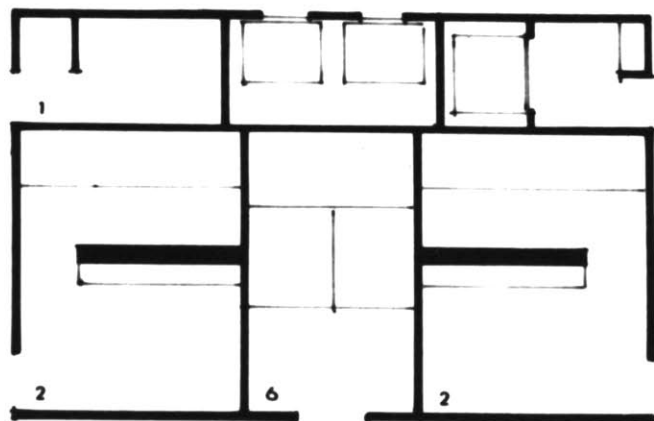


6 STAIR B

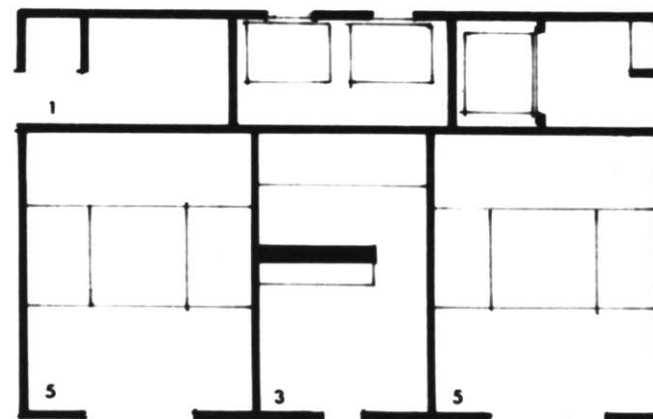
# CORE ELEMENTS

$\frac{1}{8}'' = 1'$

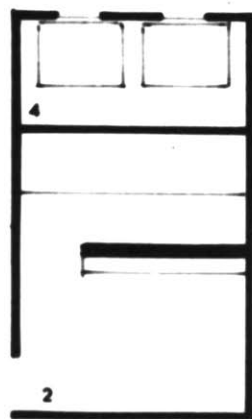
PLATE 9



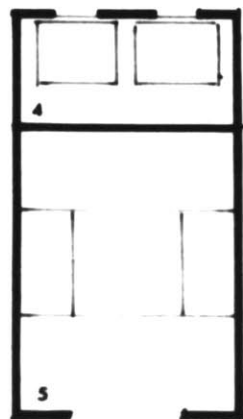
**3** (1 and 2 are shown on Plate 15.)



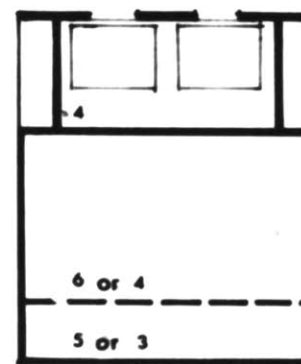
**4**



**5**



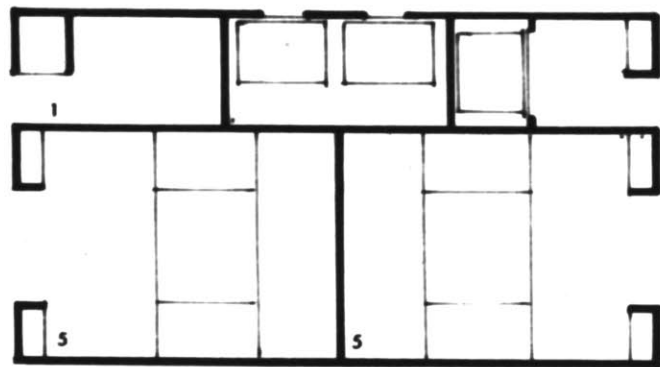
**6**



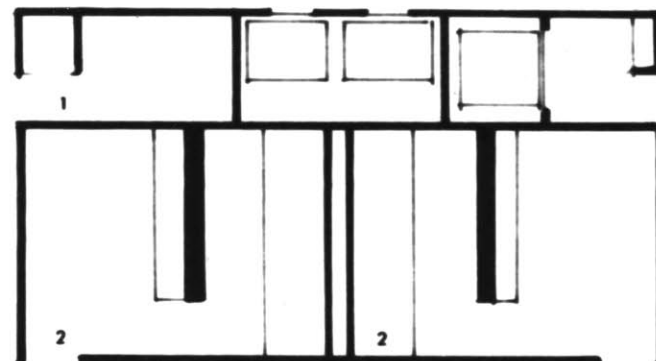
**7**

## CORE VARIANTS

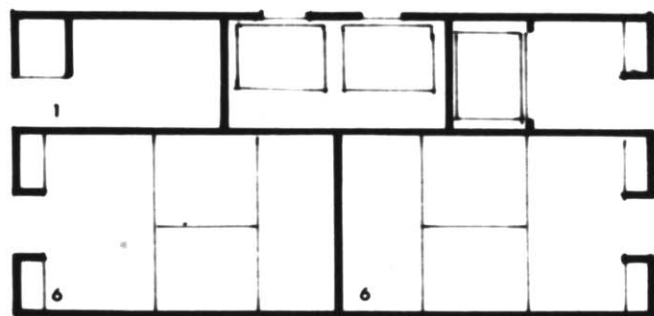
$$\frac{1}{16}'' = 1'$$



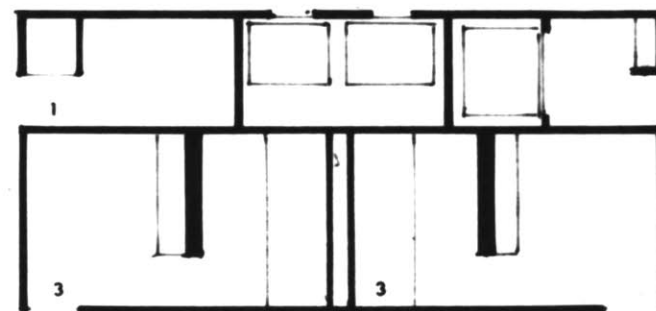
8



9



10

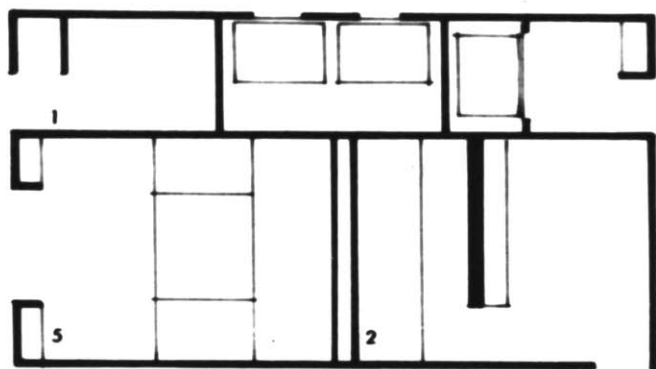


11

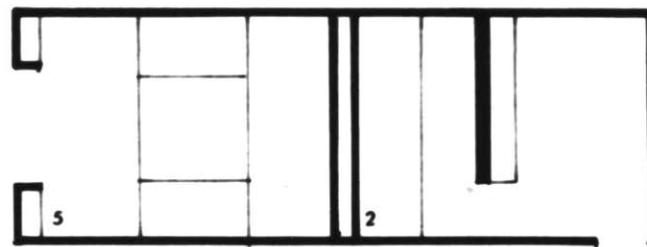
# CORE VARIANTS

$\frac{1}{16}'' = 1'$

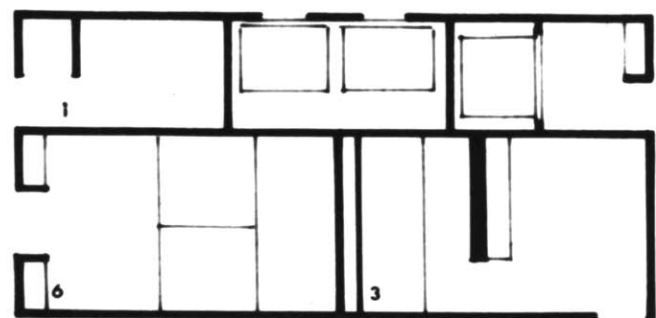
PLATE 11



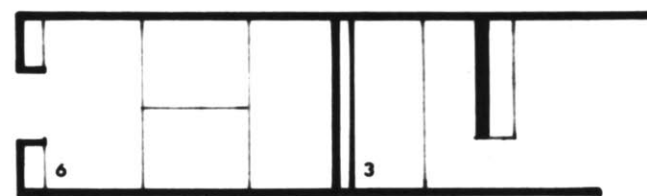
12



13



14



15

# CORE VARIANTS

$\frac{1}{16}'' = 1'$

PLATE 12

MAXIMUM SPACING  
NO SPRINKLERS

MINIMUM SPACING

MAXIMUM SPACING  
WITH SPRINKLERS

PINWHEEL SPACING  
NO SPRINKLERS

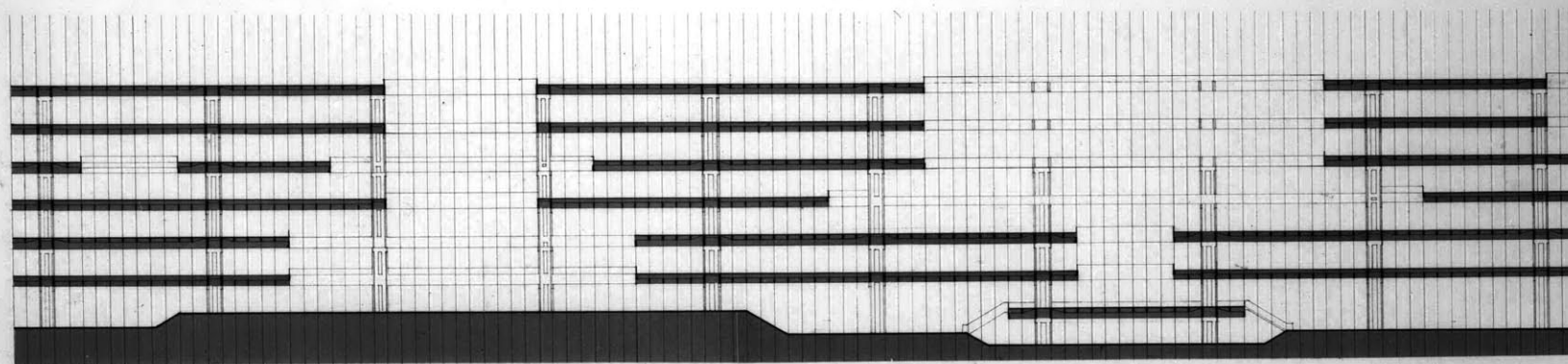
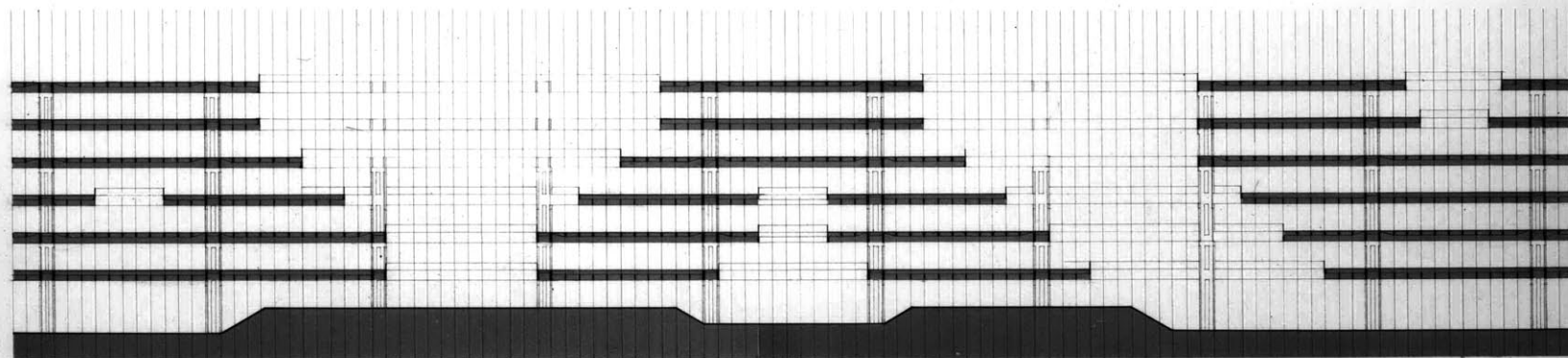
CORE SPACING VARIANTS

0 10 30 60 120

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966



SECTIONAL VARIANTS

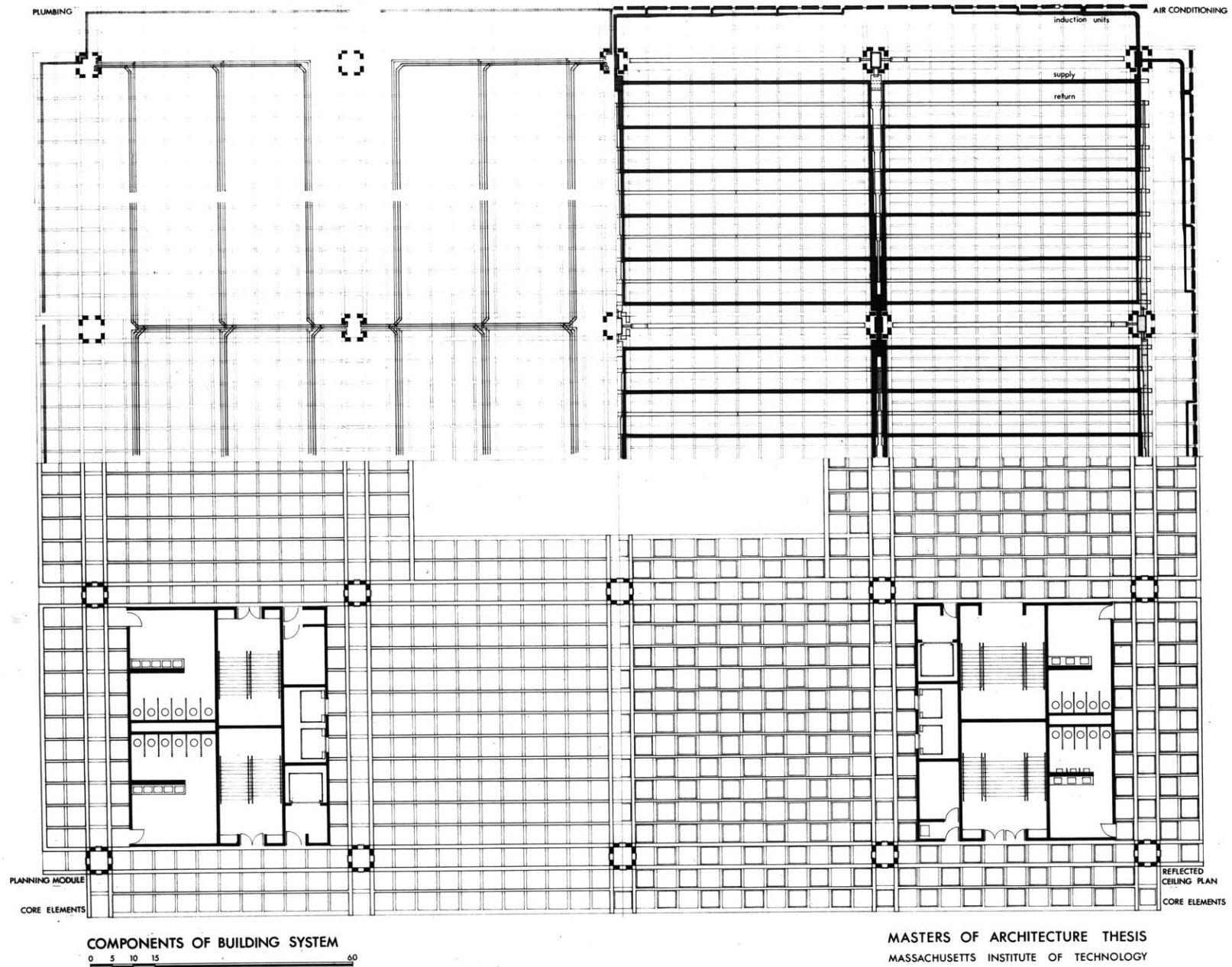
0 5 10 15 60

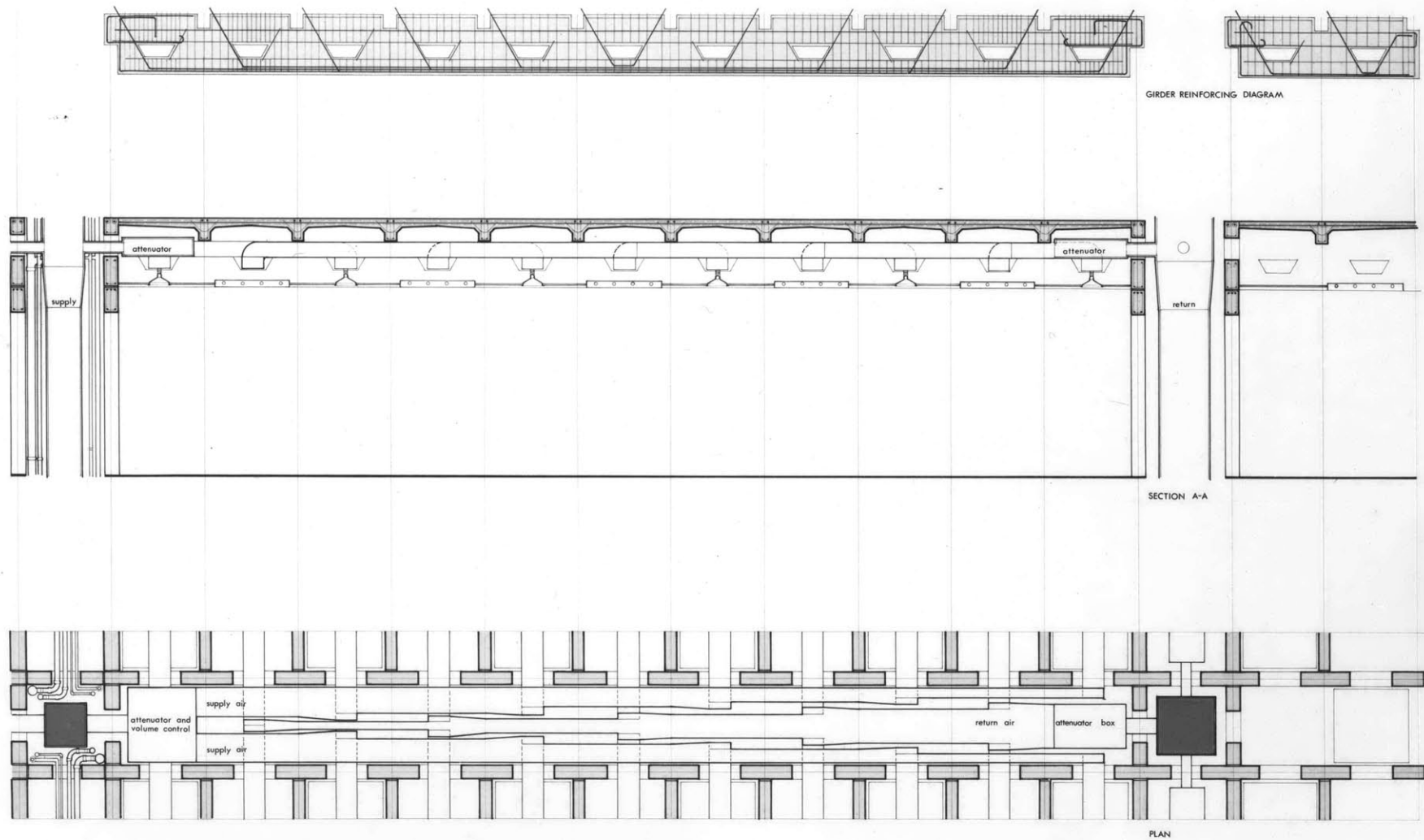
MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966







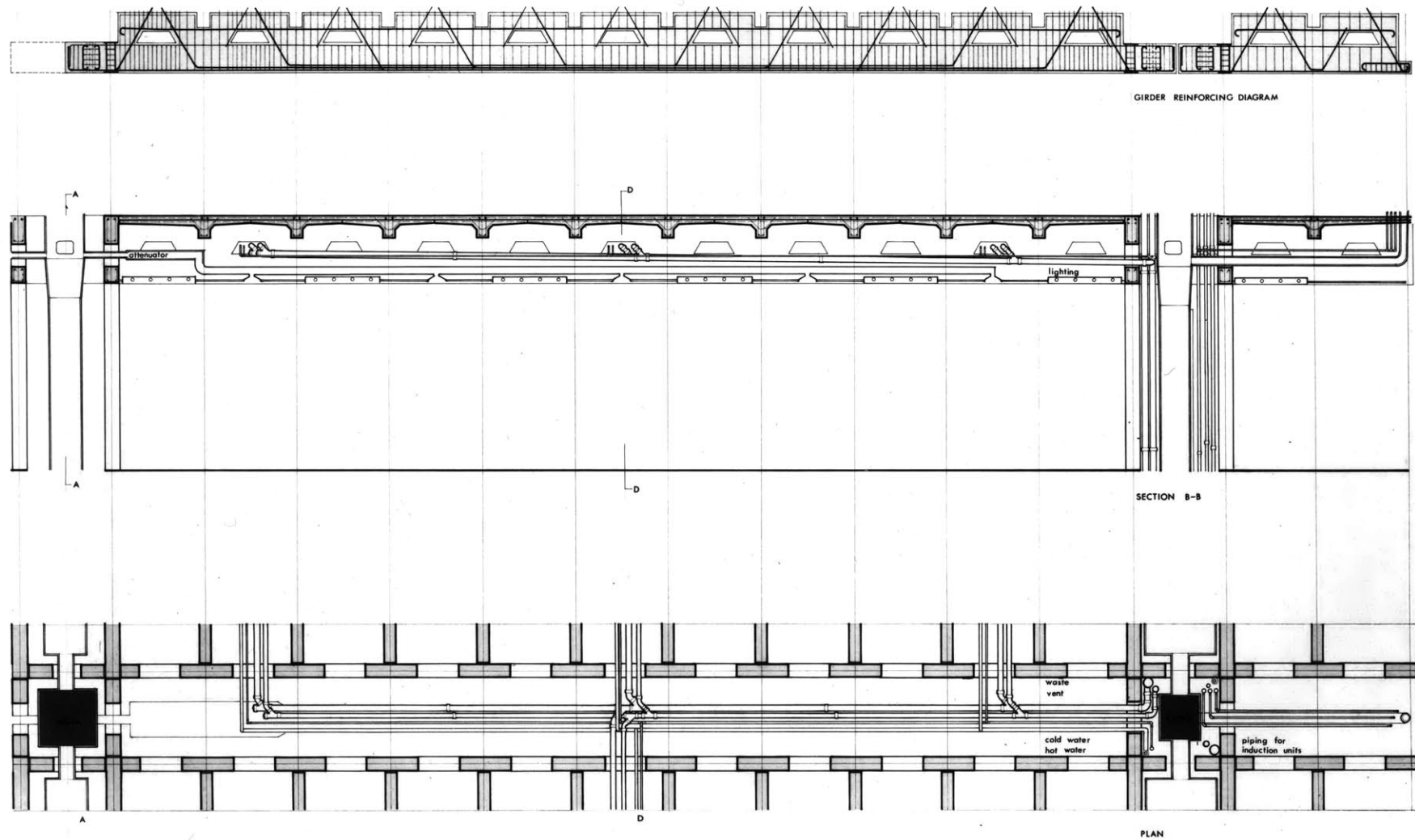
MECHANICAL STRUCTURAL INTEGRATION AT SECTION A-A

0 1 5 10

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966



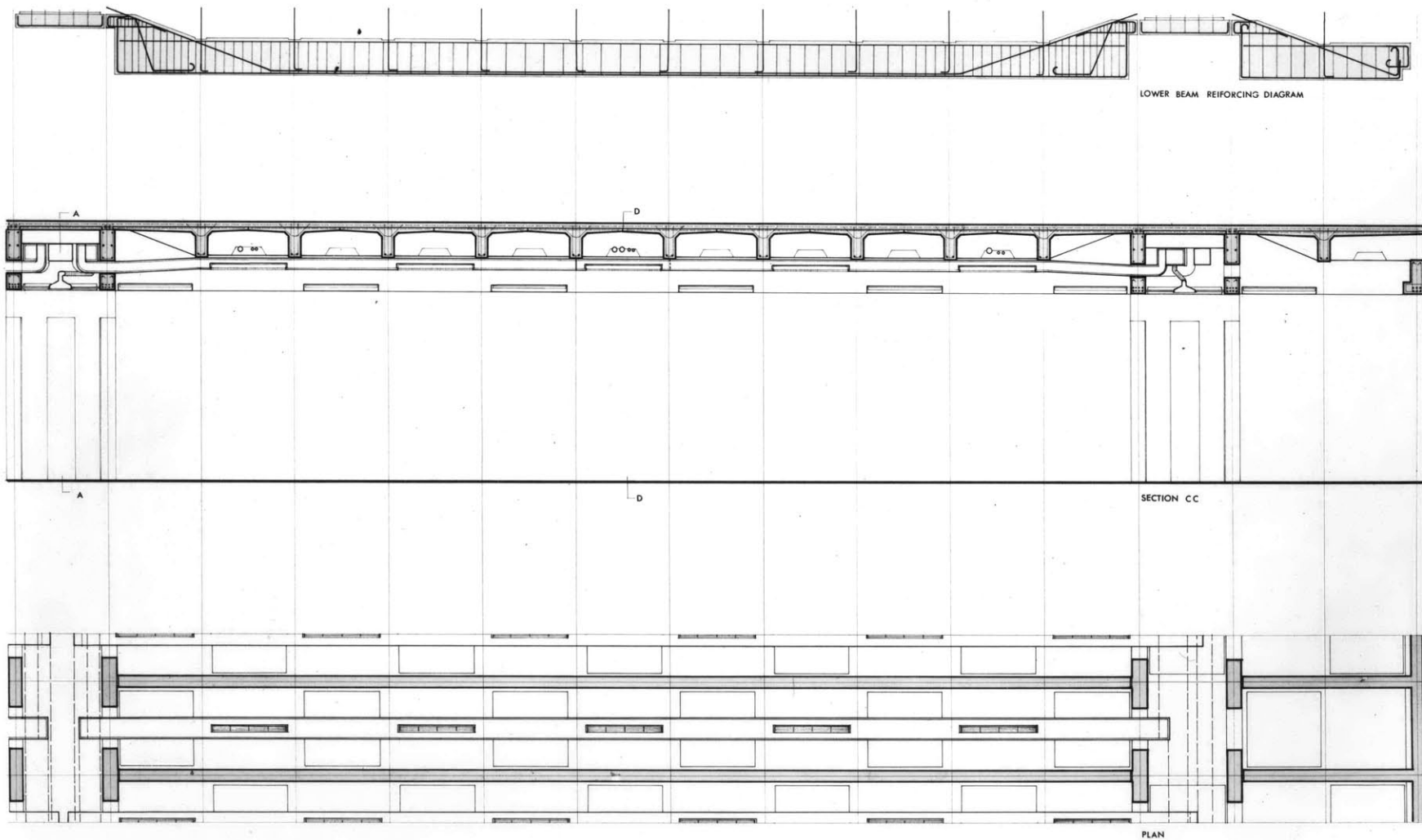
MECHANICAL STRUCTURAL INTEGRATION AT SECTION B-B

0 1 5 10

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966



MECHANICAL STRUCTURAL INTEGRATION AT SECTION C-C

0 1 5 10

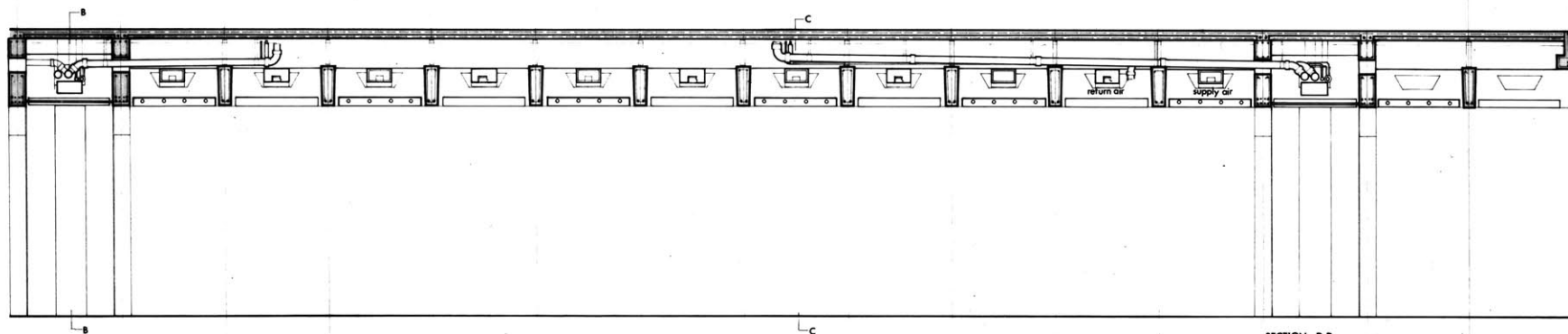
MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

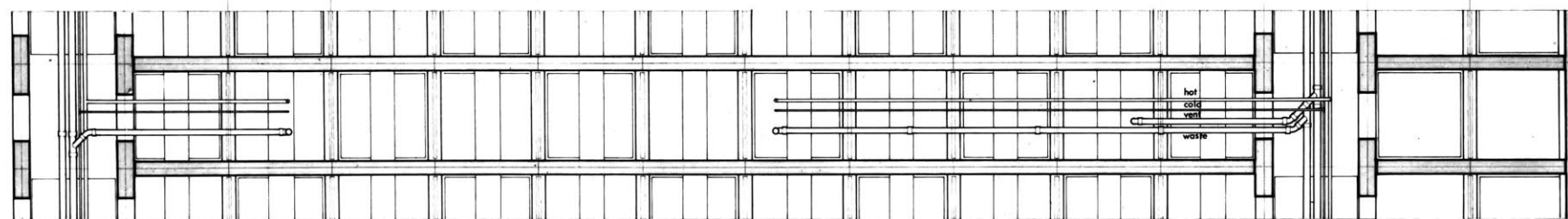
1966



TEE BEAM REINFORCING DIAGRAM



SECTION D-D



PLAN

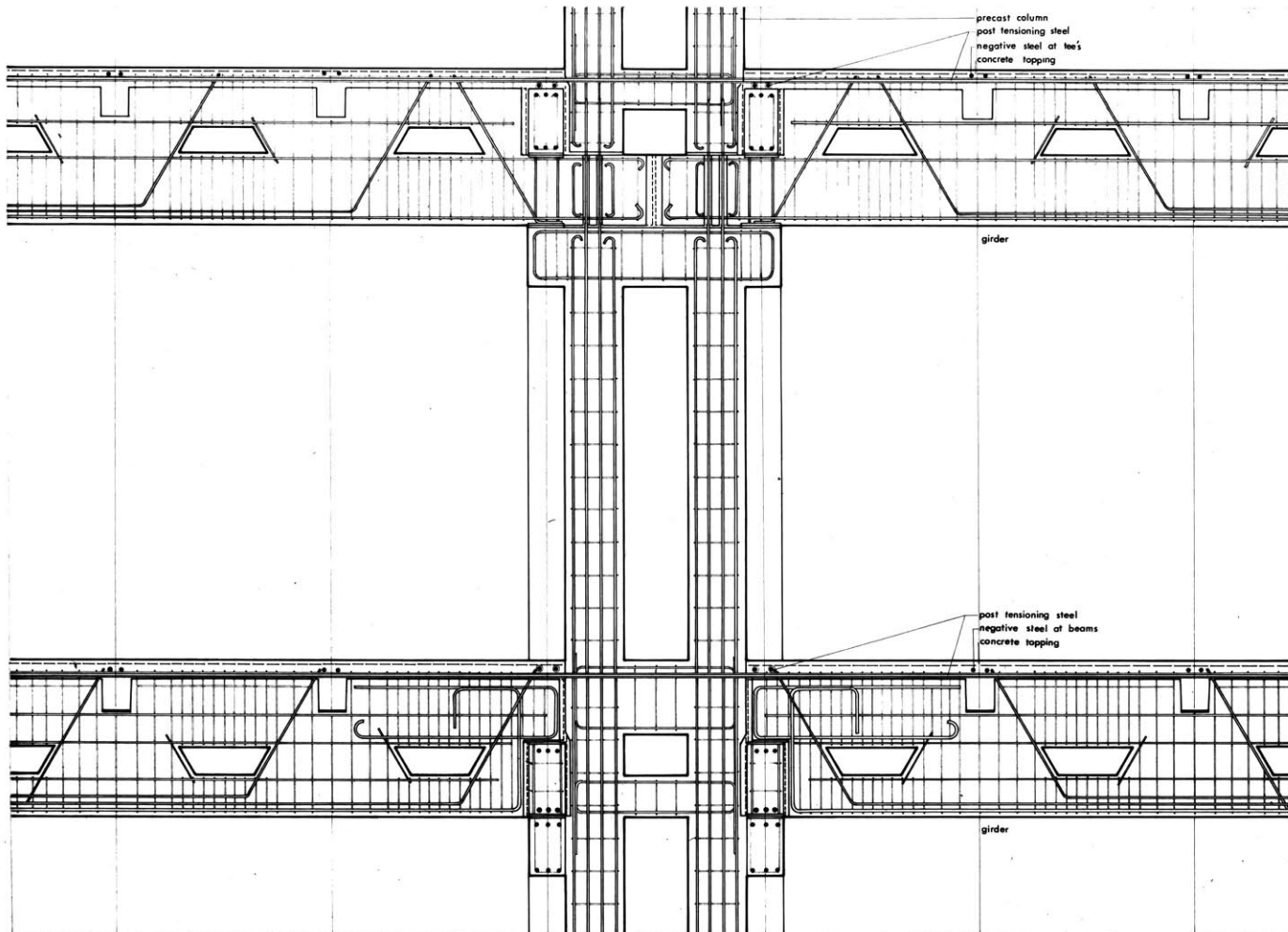
MECHANICAL STRUCTURAL INTEGRATION AT SECTION D-D

0 1 5 10

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966

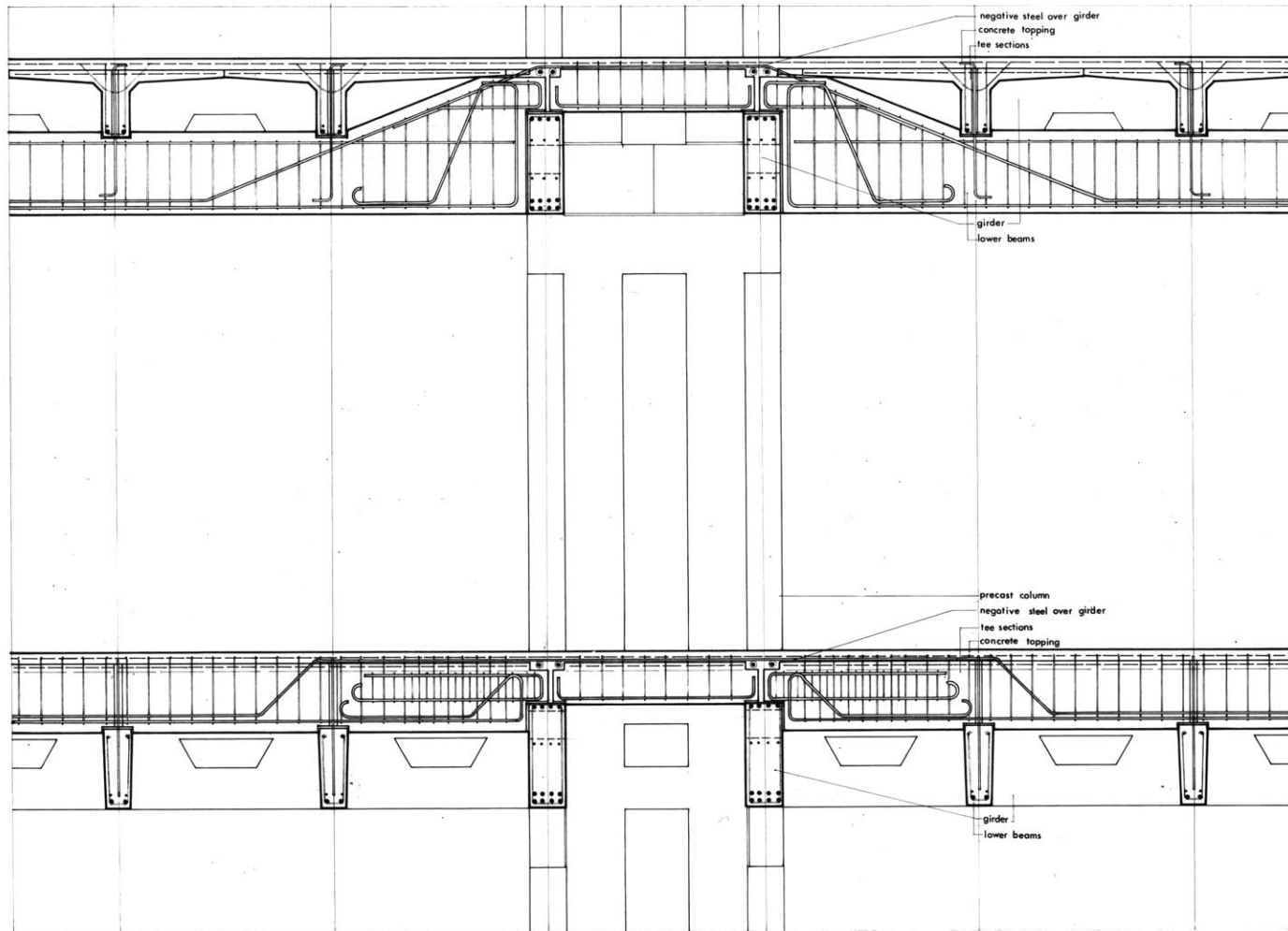


CONSTRUCTION DETAILS  
0 1 2 3 4 5

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966

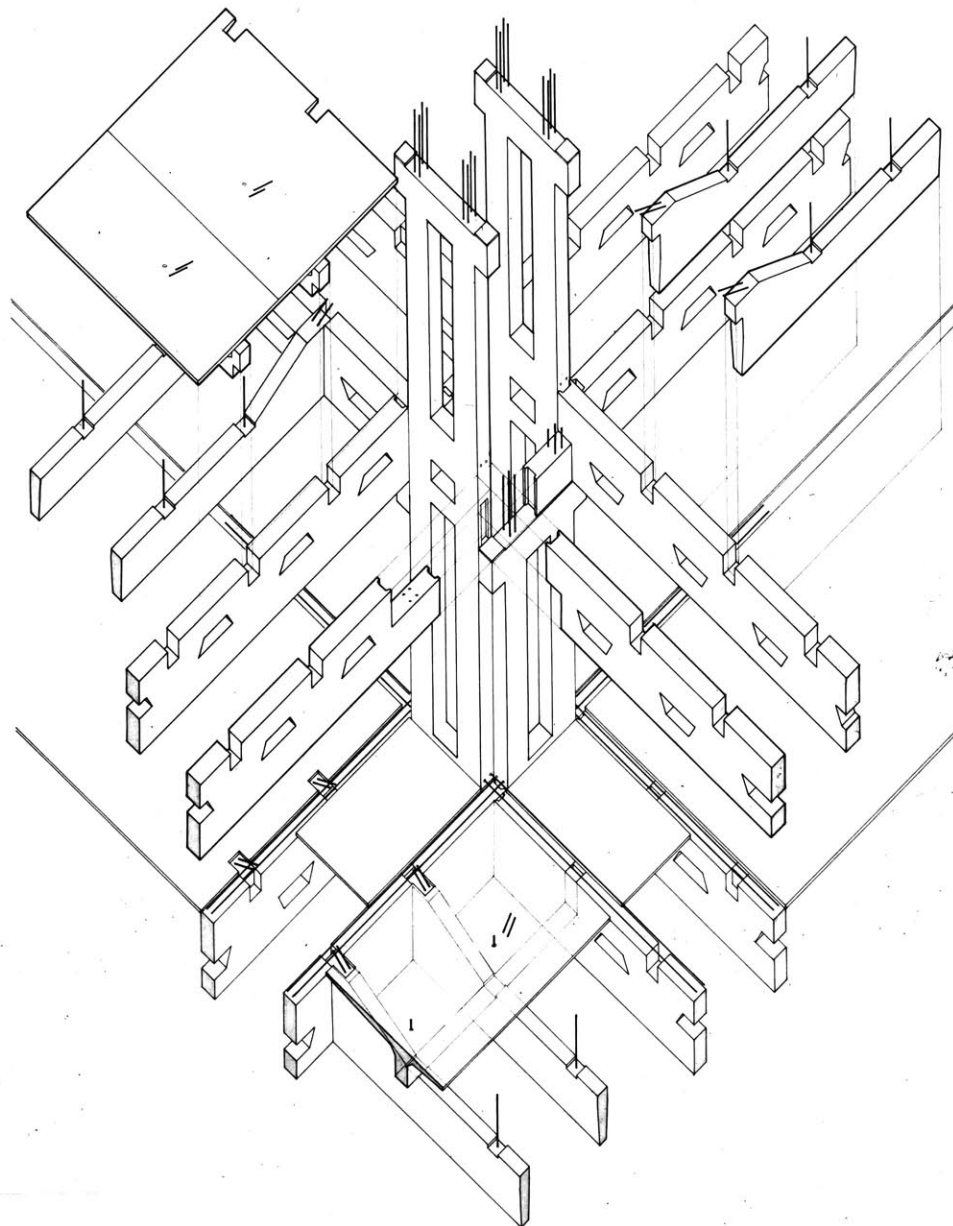


CONSTRUCTION DETAILS  
0 1 2 3 4 5

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CHARLES F. DAVIS, III

1966



AXONOMETRIC OF ASSEMBLAGE

0 1 2 3 4 5 10

MASTERS OF ARCHITECTURE THESIS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

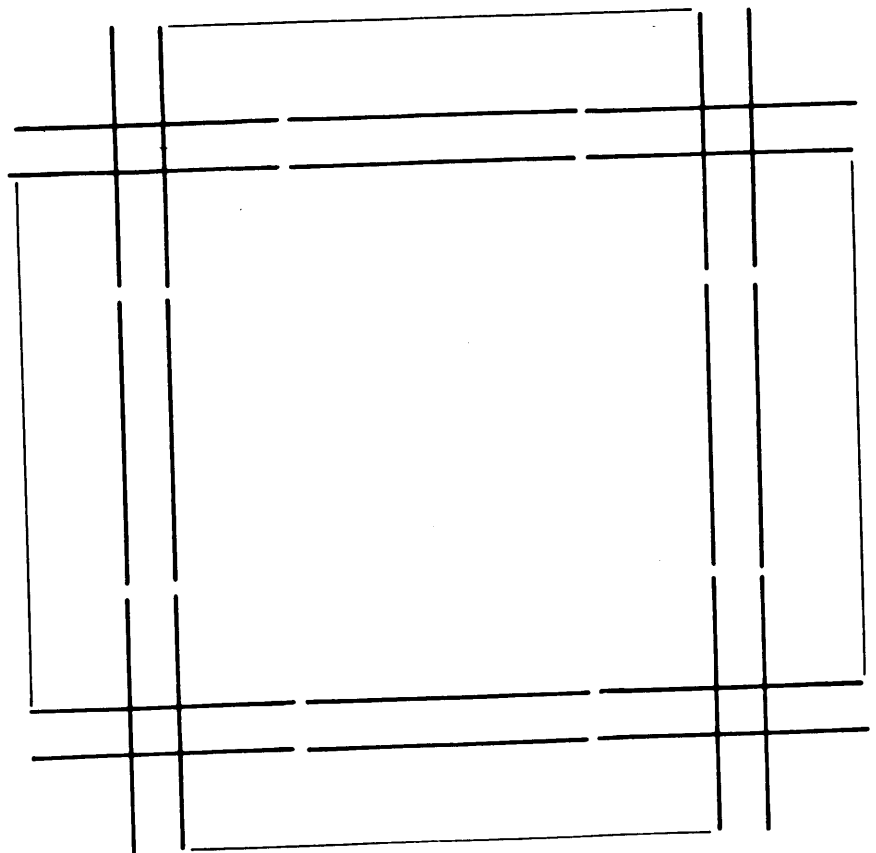
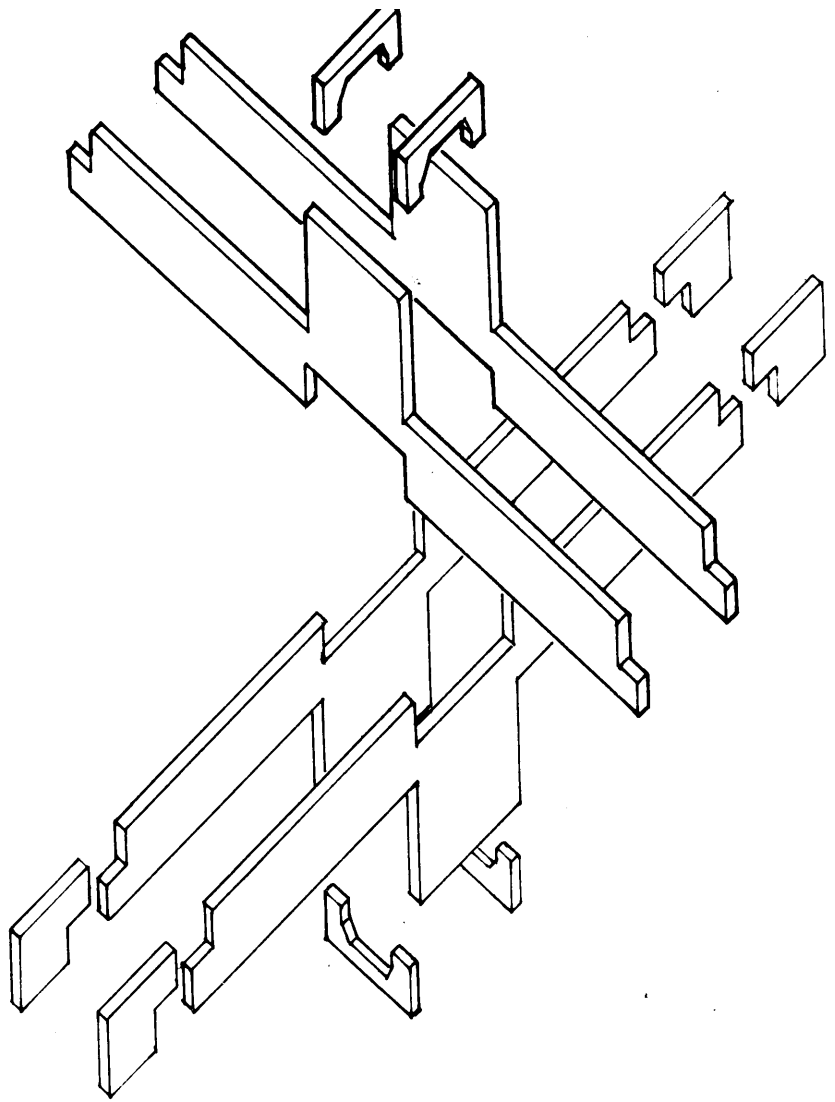
CHARLES F. DAVIS, III

1966

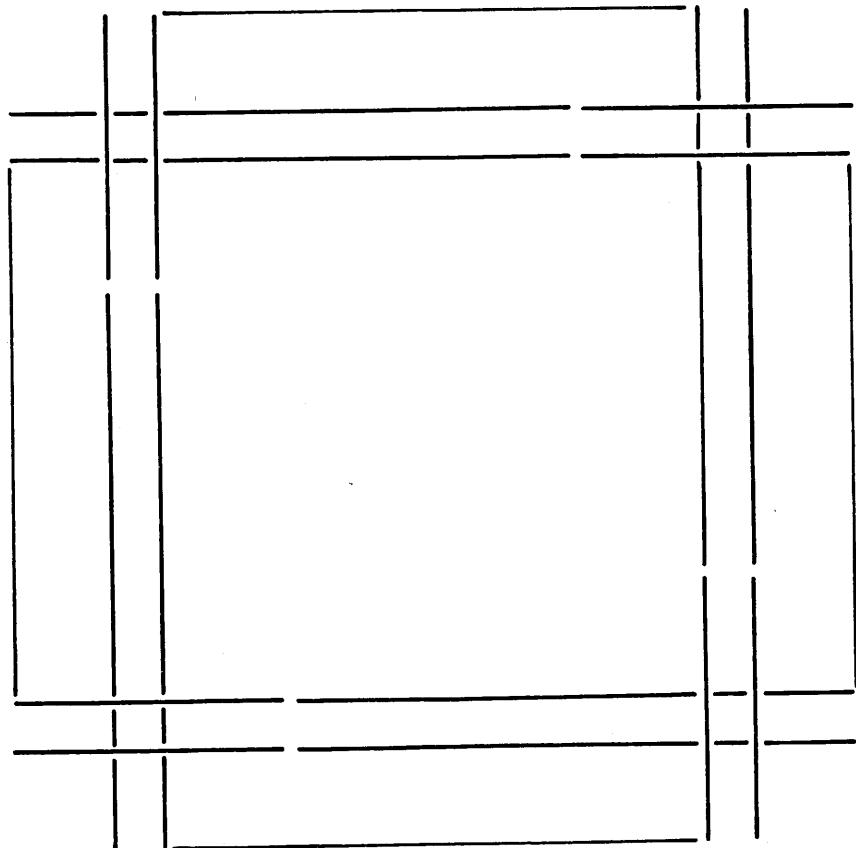
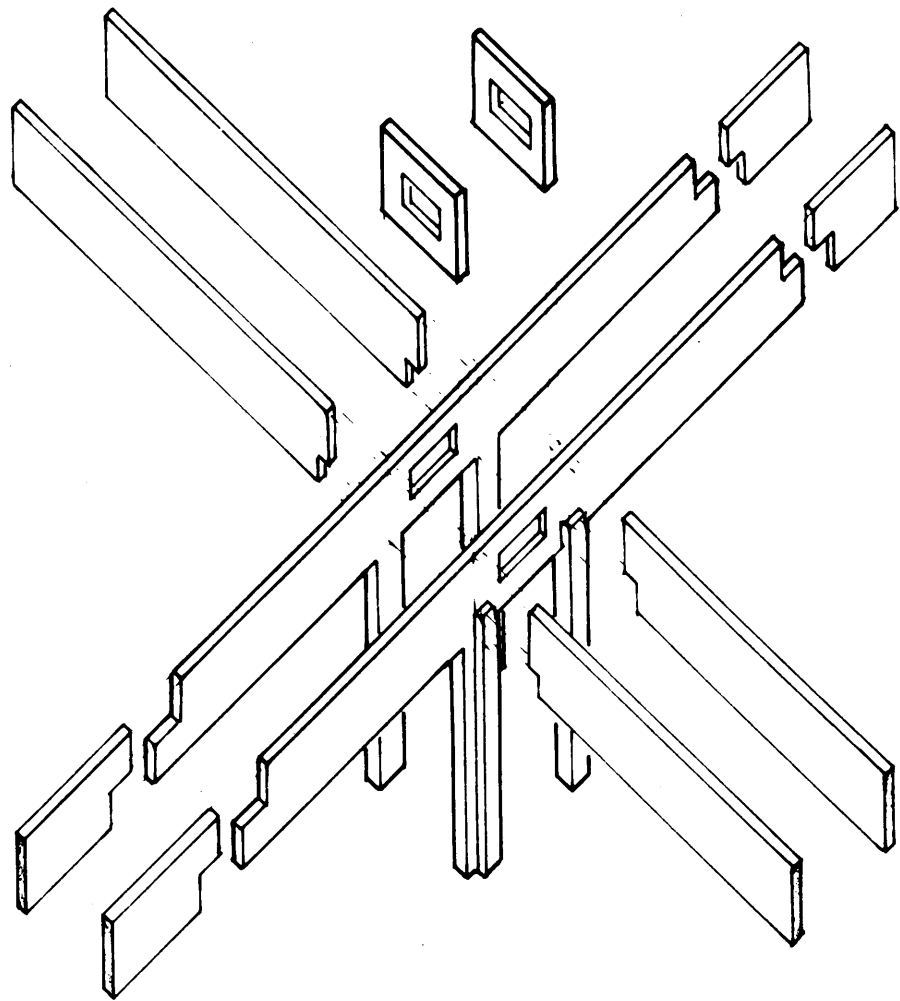


## APPENDIX A

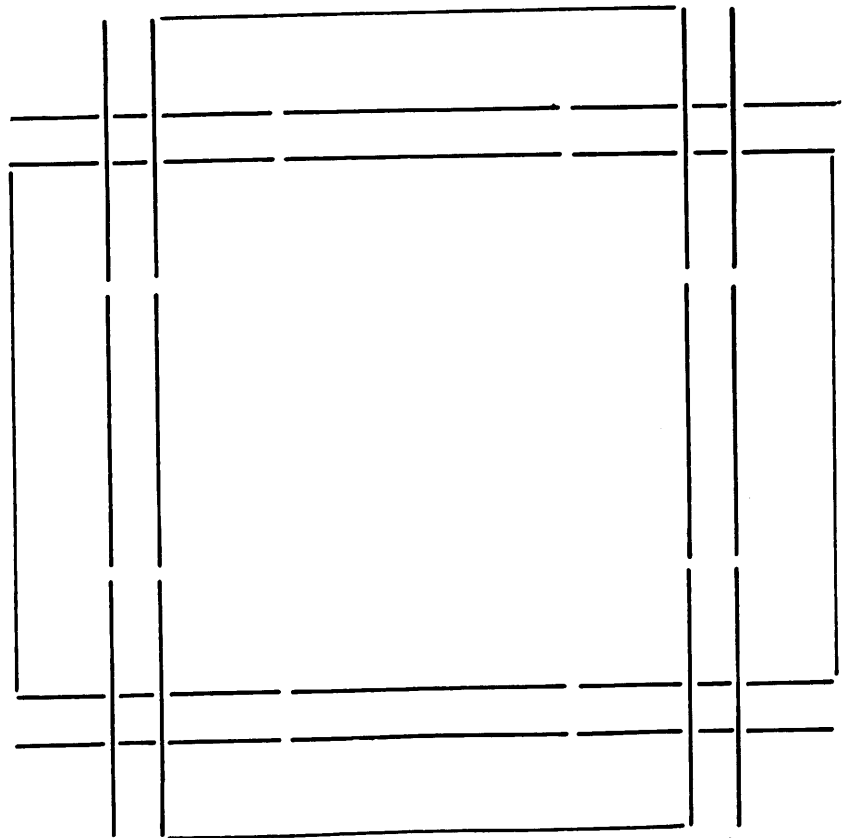
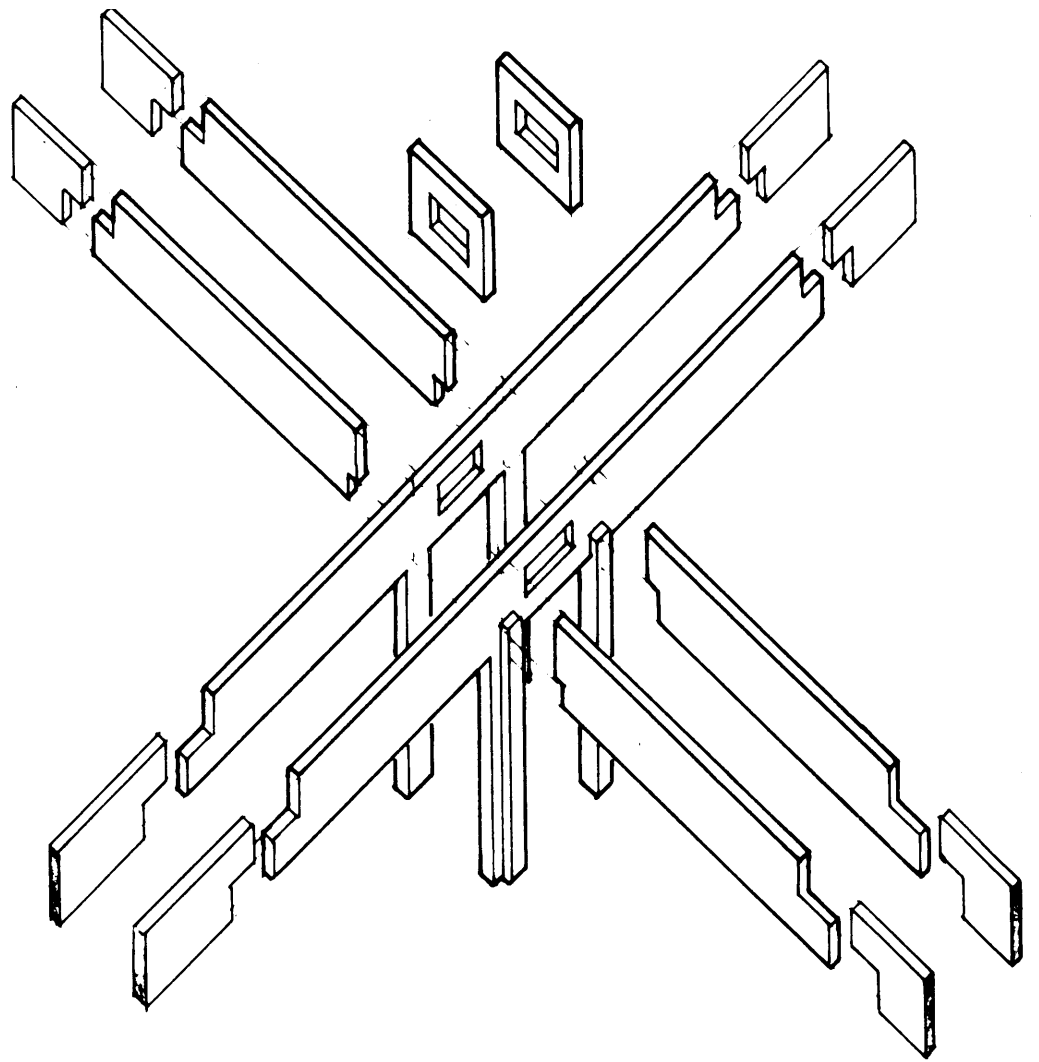
### ALTERNATE GIRDER DESIGNS



ALTERNATE 1

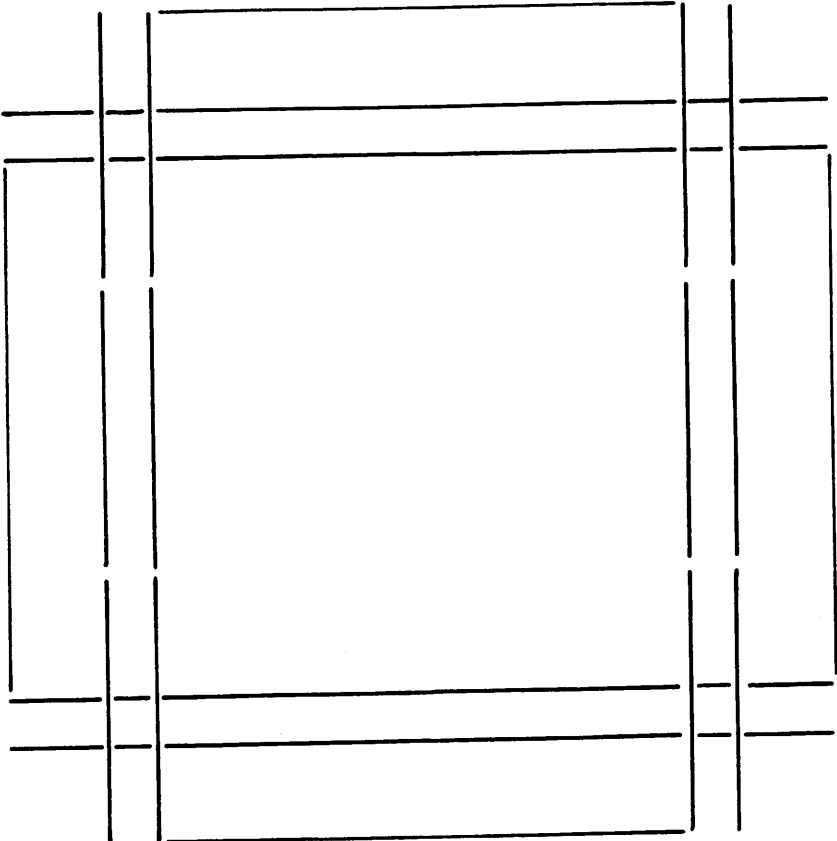


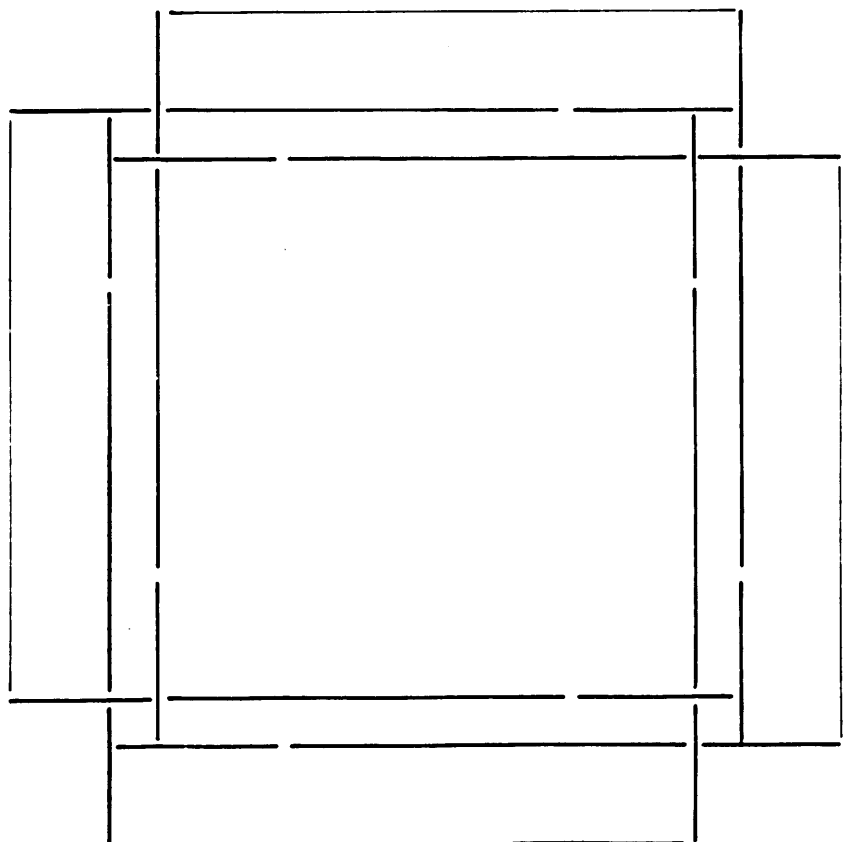
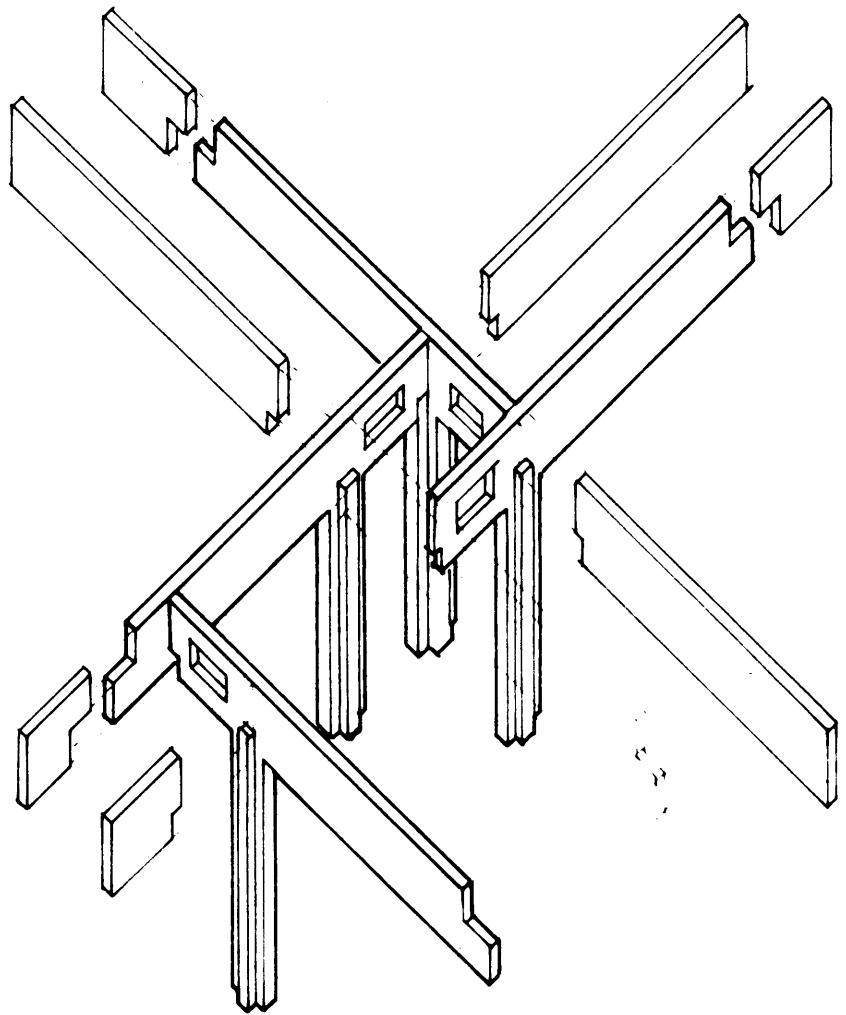
ALTERNATE 2



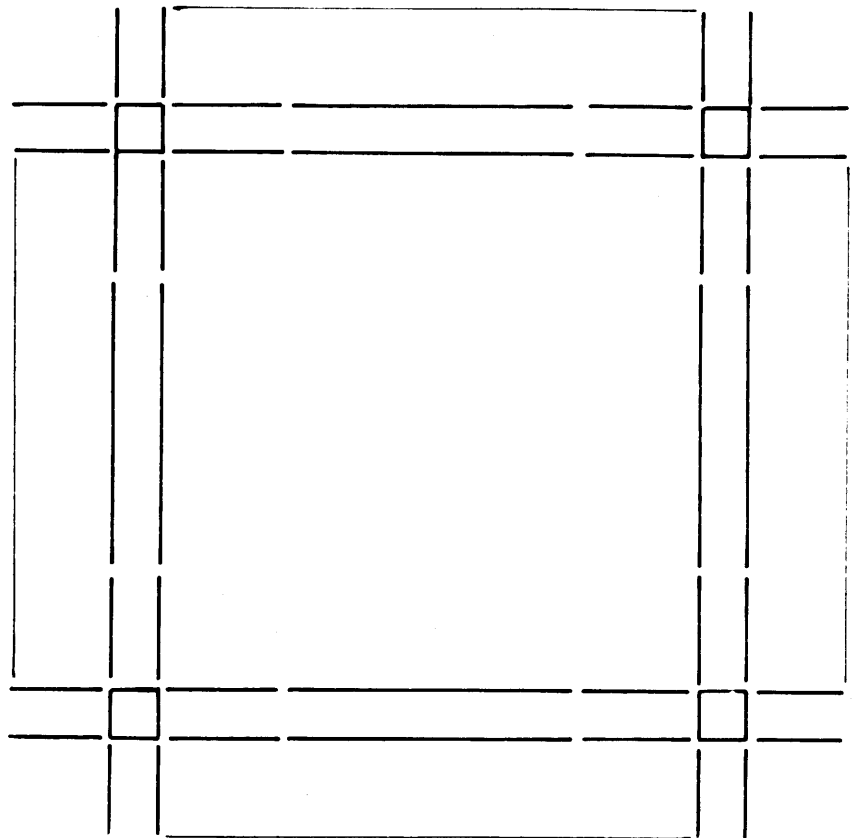
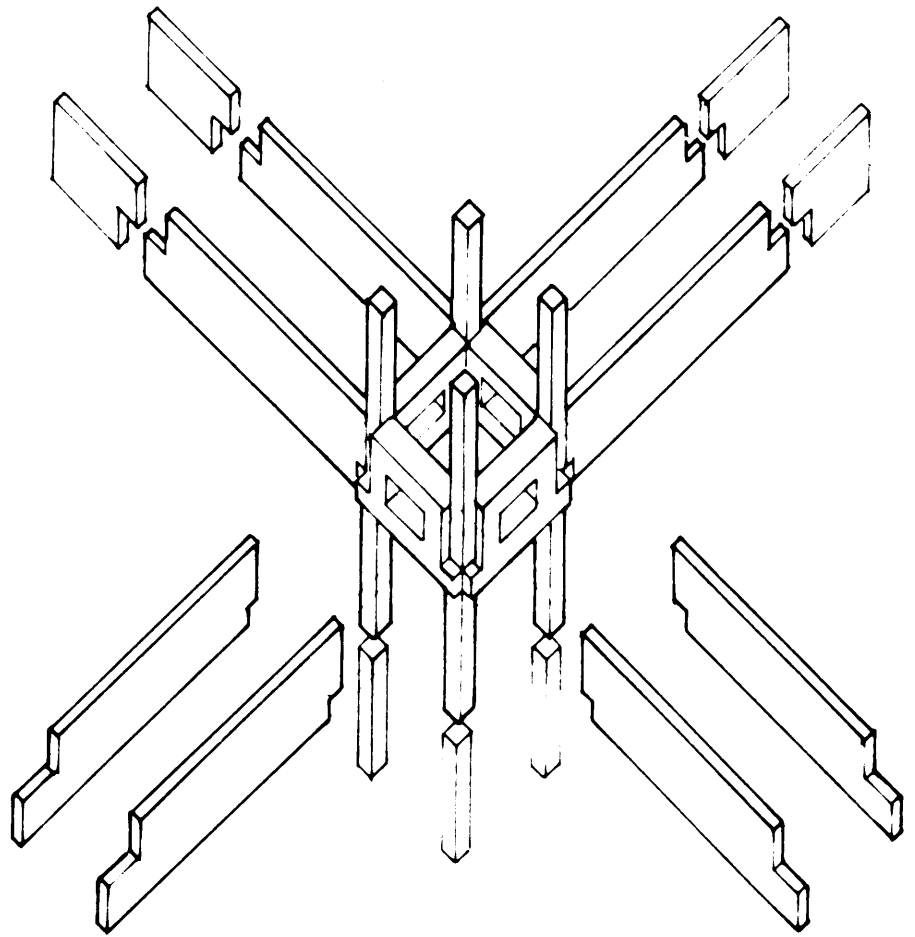
ALTERNATE 3a

ALTERNATE 3b

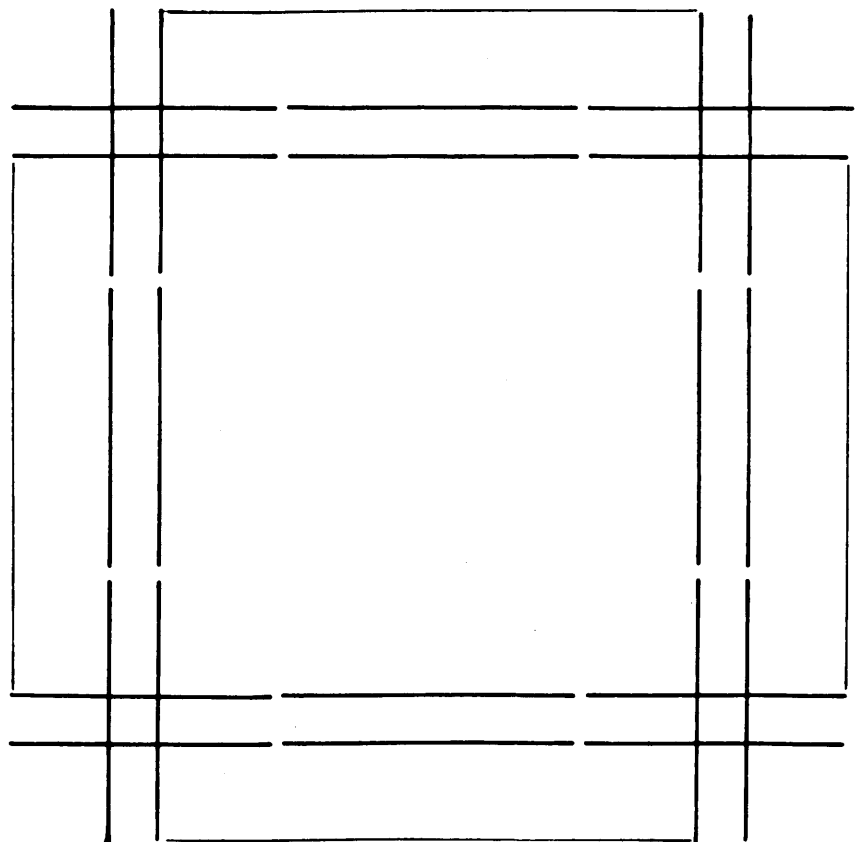
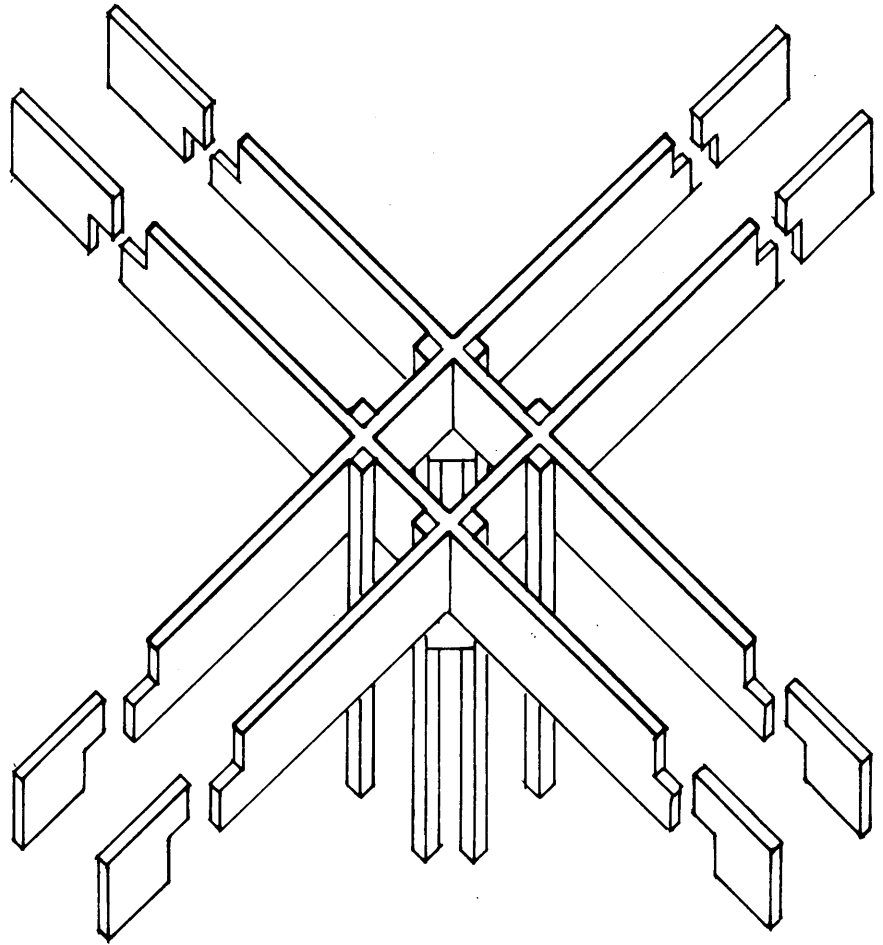




ALTERNATE 4



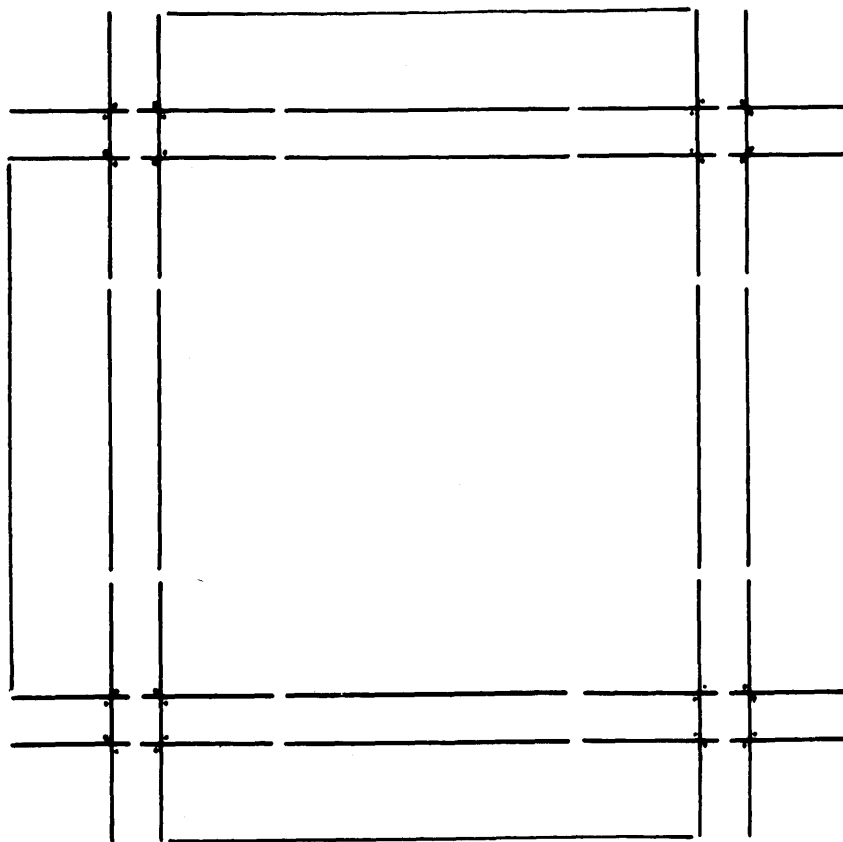
ALTERNATE 5



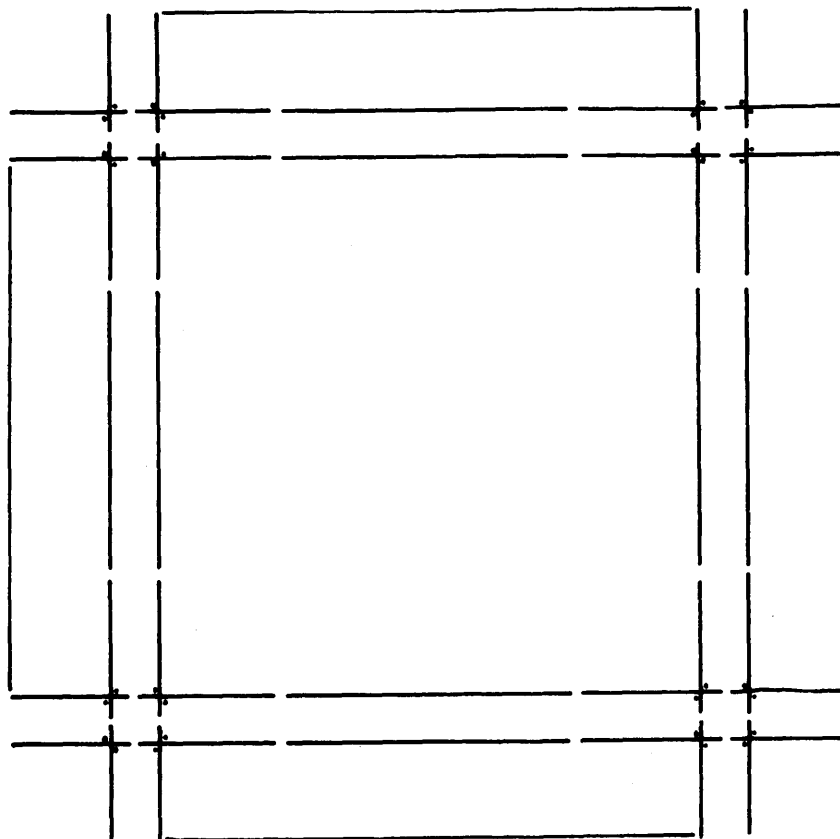
ALTERNATE 6a



ALTERNATE 6b



ALTERNATE 6c



## **APPENDIX B**

### **ALTERNATE COLUMN DESIGNS**

## **APPENDIX C**

### **FORMWORK FOR PRECAST CONCRETE ELEMENTS**

